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A VERSATILE USER-ORIENTED CLOSED BOMB DATA REDUCTION PROGRAM (CBRED)

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September 1977

USA ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
USA BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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A versatile digital computer program was developed to provide linear burning rate information on propellants based on pressure-time records obtained from closed bomb firings. Some of the unique features of the program are: a treatment of heat loss based on radiative and convective heat transfer, capability of using single valued or tabular thermodynamic input, allowance for web deviation in the propellant sample, allowance for ignition deviation (flame spread) of the propellant sample, allowance for possible simultaneous burning of

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propellant and ignition aid, allowance for tabular input of propellant surface versus mass fraction burned (to accommodate unusual geometries), and capability to treat vented vessel operations. The program was set up to operate on an interactive basis on a PDP 11/20 laboratory computer. In practice, once the program is called, the operator is guided in his choice of parameters (thermochemistry, heat loss, ignition deviation, etc.) by a series of prompts. A program overview is presented along with a description of equations, a derivation of the equations, and copies of program output and program listing.

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LIST OF SYMBOLS

Fortran Symbol	Symbol	Definition	Units
CAID	c_a	starting weight of ignition aid	lb
CPROP CNGWT	c_p	starting weight of propellant	lb
	g	gravitational constant (used as a conversion factor)	ft/sec^2
H	h_c	convective heat transfer coefficient	$Btu/in.^2\text{-}^oR$
SPACE2(3)	h_r	radiative heat transfer coefficient	$Btu/in.^2\text{-}^oR^4$
TOTMOL	m_T	total moles of gas in chamber	lb-mol
RMOL	$\dot{m}_T$	rate of change of total moles of gas in the chamber	mol/sec
RATE	r	linear burning rate of the propellant	in./sec
TIGN	t_{ig}	time of propellant ignition	msec
TMAX	t_{pm}	time of maximum pressure	msec
Y(5)	w_a	weight of ignition aid burned	lb.
Y(3)	w_{al}	weight of ignition aid combustion products in the chamber	lb
DY(5)	$\dot{w}_a$	ignition aid mass burning rate ($\dot{w}_a$=AP^n)	lb/sec
DY(3)	$\dot{w}_{al}$	rate of change of ignition aid combustion products in the system ($\dot{w}_{al}$=$\dot{w}_a$-w_a $\dot{w}_n/w_s$)	lb/sec
Y(2)	w_i	weight of igniter combustion products in the chamber	lb

LIST OF SYMBOLS

FORTRAN Symbol	Symbol	Definition	Units
DY(2)	$\dot{w}_i$	rate of change of igniter combustion products ($\dot{w}_i = - w_i \dot{w}_n/w_s$)	lb/sec
DNN	$\dot{w}_n$	mass discharge rate through the nozzle	lb/sec
Y(6)	w_p	weight of propellant burned	lb
Y(4)	w_{pl}	weight of propellant combustion products in the chamber	lb
DY(6)	$\dot{w}_p$	mass burning rate of the propellant	lb/sec
DY(4)	$\dot{w}_{pl}$	rate of change of propellant combustion products in the chamber (vented chamber operation) ($\dot{w}_{pl} = \dot{w}_p - w_{pl} \dot{w}_n/w_s$)	lb/sec
Y(1)	w_r	weight of air in the chamber	lb
DY(1)	$\dot{w}_r$	rate of change of air in the system ($\dot{w}_r = - w_r \dot{w}_n/w_s$)	lb/sec
WSYS	w_s	weight of gases in the chamber $w_s = w_r + w_i + w_{al} + w_{pl}$	lb
DWSYS	$\dot{w}_s$	rate of change of the weight of gases in the system	lb/sec
DB	x	distance burned into the grain	in.
Y(8-12)	x_n	distance burned into the grain for the n-th charge increment (n has values of 1-5)	in.
SPACE1(10)	A_t	effective throat area(sonic control assumed)	in.^{2}
SPACE2(2)	A_w	bomb wall surface area	in.^{2}
CP	C_p	heat capacity at constant pressure	Btu/lb.^{o}F

LIST OF SYMBOLS

FORTRAN Symbol	Symbol	Definition	Units
CVP	C_v	heat capacity at constant volume	Btu/lb - ^oF
DCVP	$\dot{C}_v$	rate of change of heat capacity at constant volume	Btu/lb - ^oF-sec
CSTAR	C*	characteristic discharge velocity	ft/sec
OD	D	initial grain diameter	in.
PD	D_p	initial perforation diameter	in.
OOD	D'	instantaneous grain diameter (D' = D - 2x)	in.
PPD,PRFD	D'_p	instantaneous perforation diameter ($D'_p = D_p + 2x$)	in.
E	E	end area of grain	in.^{2}
	E^*_{cv}	energy of gases in the chamber	
	E^*_p	energy from combustion of the propellant	
HTL1	H_L	total heat loss to walls of the chamber	Btu
ARP	$\dot{H}_L$	instantaneous heat loss rate	Btu/sec
H	$\bar{\dot{H}}_L$	average heat loss rate	Btu/sec
G	$\dot{H}_{Lc}$	convective heat loss rate	Btu/sec
HTL	$\dot{H}_{Lr}$	radiative heat loss rate	Btu/sec
GL	L	initial grain length	in.
GGL	L'	instantaneous grain length	in.

* Variables used in derivation only

LIST OF SYMBOLS

FORTRAN Symbol	Symbol	Definition	Units
XMA	M_a	molecular weight of ignition aid combustion products	NA
XMI	M_i	molecular weight of igniter combustion products	NA
XMP	M_p	molecular weight of propellant combustion products	NA
	M_r	molecular weight of air (defined as 29)	NA
XMW	M_s	molecular weight of gases in the system	NA
Y(7),P	P	pressure	psia
DP	$\dot{P}$	rate of change of pressure with respect to time	psia/sec
PMAX	P_m	experimentally measured maximum pressure in the system	psia
P	P_{st}	stagnation pressure	psia
PTHEO	P_{0s}	theoretically computed maximum pressure in the system	psia
RSYS	R_s	gas constant for the system ($R_s = R_u m_T / w_s$)	in.-lb/lb$^{\circ}$F
DR	$\dot{R}_s$	rate of change of gas constant for the system ($\dot{R}_s = R_u/w_s(\dot{m}_T - m_T\dot{w}_s/w_s)$)	in.-lb/lb-$^{\circ}$F-sec
RU	R_u	universal gas constant	in.-lb/mol$^{\circ}$F
AAB,S	S_t	instantaneous propellant surface area	in.^{2}

LIST OF SYMBOLS

FORTRAN Symbol	Symbol	Definition	Units
AB	S_{tn}	instantaneous surface area of nth charge increment	in.^{2}
TSYS	T_s	gas temperature in the chamber (computed as ^oK; note also that $^oR=^oF$ +459.69)	^oR
TSYS	T_{st}	stagnation temperature	^oF
SPACE1(36)	T_w	bomb wall surface temperature	^oR
TAID, T5	T_{0a}	isochoric adiabatic flame temperature of the ignition aid	^oR
T6,TZD	T_{0p}	isochoric adiabatic flame temperature of the propellant	^oR
BVOL	V_b	empty bomb volume	in.^{3}
VSYS	V_s	system volume	in.^{3}
DVSYS	$\dot{V}_s$	rate of change of system volume $\dot{V}_s=-w_s\dot{\eta}-\eta\dot{w}_s+(\dot{w}_a+\dot{w}_p)/\rho$	in.^{3}/sec
WID,WOD	W	initial propellant web	in.
ALPHA	α	angle used in multiperforated grain surface calculations (MPGSC) defined in Appendix C	deg
BETA	β	angle used in MPGSC, defined in Appendix C	deg
GAM1	Γ	ratio of specific heats	NA
ETA	η	propellant covolume	in.^{3}/lb
DETA	$\dot{\eta}$	rate of change of propellant covolume	in.^{3}/lb-sec
THETA	θ	angle used in MPGSC, defined in Appendix C	deg

LIST OF SYMBOLS

Fortran Symbol	Symbol	Definition	Units
RHO	ρ	solid propellant density	lb/in.^{3}
CPGM2	Γ	a function of the specific heat ratio defined in Appendix D	NA

I. INTRODUCTION

Among the parameters of interest to the interior ballistician are the burning rate and chemical energy of the propellant used in propelling charges. These parameters must be known to predict the performance to be expected from a given gun-ammunition system.[1,2] Reliable data on the chemical energy of the propellant may be obtained from thermodynamic calculations based on the chemical composition and heats of formation of the propellant ingredients.[3,4] Propellant burning rates, however, cannot be predicted with similar reliability although various efforts at predicting burning rates from chemical compositions,[5,6,7] thermochemistry[8] and chemical kinetics have been and are being

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[1] *J. Corner, M. A., PhD, Theory of the Interior Ballistics of Guns, New York, John Wiley and Sons, Inc., 1950.*

[2] *Paul G. Baer and Jerome M. Frankle, "The Simulation of Interior Ballistic Performance of Guns by Digital Computer Program," Ballistic Research Laboratories Report No. 1183, December 1962, AD #299980.*

[3] *A. C. Haukland and W. M. Burnett, "Sensitivity of Interior Ballistic Performance to Propellant Thermochemical Parameters," Proceedings of the Tri-Service Gun Propellant Symposium, 11-13 October 1972, Picatinny Arsenal, Dover, NJ, Vol 1, Section 7.3.*

[4] *Paul G. Baer, Ingo W. May, and Jerome M. Frankle, "A Comparison of Several Predictive Approaches in Charge Establishment for Large Caliber Artillery Systems," Proceedings of the 11th JANNAF Combustion Meeting, Jet Propulsion Laboratory, Pasadena, CA., September 1974, Vol 1; C.P.I.A. Publication 261, December 1974, The Chemical Propulsion Information Agency, Silver Spring, Md.*

[5] *William H. Tschappat, Lt.-Col, Ord. Dept., Text-Book of Ordnance and Gunnery, 1st Ed., New York, John Wiley and Sons, Inc., 1917, pp. 111-118.*

[6] *Albert A. Bennett, PhD, "Tables of Interior Ballistics," Ordnance Department Pamphlet No. 2039, April 1921.*

[7] *D. W. Riefler and D. J. Lowery, "Linear Burn Rates of Ball Propellants Based on Closed Bomb Firings," Ballistic Research Laboratories Contractor Report No. 172, August 1974.* (AD #921704L)

[8] *Henri Muraour, "Chemie Physique sur la Reaction Entre La Temperature de la Explosion d' une Poudre et sa Vitesse de Combostion," Comp. rend., Vol 187, 1928, pp. 289-294.*

pursued.[9-15] (See, footnote,*). Useful burning rate data, therefore, must still be obtained experimentally.

Classically, two principal methods have been used to obtain burning rate data for propellants. These are the strand burner and the closed bomb. Both involve the burning of propellant samples in steel containers of sufficient strength to withstand high pressures. In a strand burner, a single sample (strand) of propellant is burned cigarette fashion under essentially a constant pressure. In practice, this is achieved by connecting a ballast volume to the combustion chamber so that the gases given off by the propellant contribute negligibly to overall system pressure. The regression of the burning surface is measured by timing the intervals between breaking of fuse wires embedded along the length of the propellant sample. Thus each experiment yields a single average value of linear burning rate for a given pressure. To obtain burning rates for a propellant over a range of pressures, a number of experiments are required. The resultant data are fitted to some mathematical form which then allows computation of the values of the burning rate at intermediate points. The method is straight-forward (though time consuming) and has been used for many years, especially by the rocket community.

Current Army efforts on combustion modeling are centered in the Fundamentals of Combustion Task of the Energetic Materials Technology Program of the US Army Materiel Development and Readiness Command, Alexandria, VA 22333.

[9] *Ref 1, pp. 42-84 and reference therein.*

[10] *Bryce L. Crawford, Jr., Clayton Huggett, and J. J. McBrady, "The Mechanism of Burning of Double Base Propellants," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 854-862.*

[11] *Robert G. Parr and Bryce L. Crawford, Jr., "A Physical Theory of Burning of Double Base Rocket Propellants," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 929-954.*

[12] *O. K. Rice and Robert Ginell, "The Theory of Burning of Double Base Rocket Powders," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 885-917.*

[13] *R. E. Wilfong, S. S. Penner, and F. Daniels, "An Hypothesis for Propellant Burning," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 863-872.*

[14] *R. D. Geckler, "Mechanism of Combustion of Solid Propellants," Selected Combustion Problems, London, Butterworths Scientific Publications, 1954, pp. 289-339.*

[15] *D. B. Spalding, "The Theory of Solid and Liquid Propellants," Combustion and Flame, Vol 4, 1960, pp. 59-76.*

The second method of obtaining propellant burning rate data involves the closed bomb. In the closed bomb, a statistically adequate number of propellant grains are ignited and allowed to burn in a fixed volume under the pressure exerted by the propellant combustion gases. The pressure in the chamber builds up rapidly and is recorded as a function of time. From the pressure-time data it is possible to derive linear burning rate information for the propellant over a range of pressures from a single experiment, a marked advantage over the repeated tests required with the strand burner.* But where the closed bomb technique gains in experimental economy, it loses in the complexity of the data reduction method. The problem has been attacked in a variety of ways by a number of authors.[17-20] The earlier papers were aimed at providing methods for computing the data by hand. This lead to the use of a variety of simplifying assumptions both in the development of the theory and the form functions used. The more recent papers were aimed at computer solutions to the problem and, in general, provide a more complete treatment of the phenomenon. A brief bibliography of closed bomb burn rate reduction methods is included at the end of this report.

**Alternately, the data recorded may be the first derivative of pressure with respect to time vs. pressure. This is generally reduced to an average value of dp/dt (obtained at 0.250, 0.3750, 0.500, and 0.625 of the maximum pressure) which when compared with the value for a reference propellant (obtained under identical conditions) gives an idea of the burning characteristic to be expected of the sample. The "quickness" and "relative quickness"[16] values so obtained can be quite useful for correlations with weapon performance characteristics.*

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[16] *Method 801.1.1, "Quickness and Force Measurement of Propellant (Closed Bomb Method)," (Revised 21 Oct 75), Military Standard 286B, Department of Defense, Washington, DC 20301.*

[17] *C. M. Dickey, "Determination of Burning Characteristics of Propellant," E.I. duPont de Nemours and Company, Explosives Department, Burnside Laboratory, Memorandum Report No. 31 (File BL-135-101), March 1943.*

[18] *James H. Wiegand, "A Method of Calculation of the Burning Rate of Powders from dP/dt vs. P Records for closed Chambers," Ballistic Research Laboratories Report No. 546, June 1945.*

[19] *E. Haeuseler and W. Dehl, "State of Development of Testing Procedures for Propellants in the Closed Vessel," Explosivstoffe, Vol 18, 1970, pp. 41-52.*

[20] *H. Krier and S.A. Shimpie, "Predicting Uniform Gun Interior Ballistics: Part I - An Analysis of Closed-Bomb Testing," University of Illinois Technical Report AAE 74-5, July 1974. Contract DAAD-21-73-C-0540.*

The objective of the present work was to generate a comprehensive data reduction method providing more versatility than is available from any of the previous methods. The equations which were developed provide for the presence of igniter and ignition aid, as well as the ambient air present in the bomb. A more sophisticated heat loss treatment is included. Other unique features include allowance for changes in the thermodynamic characteristics of the combustion products and of web deviations in the propellant sample. In addition, the treatment allows for analysis of data from vented chamber experiments. The theory was implemented in a program written for an available laboratory computer. An attractive feature of the program is its user oriented "question and answer" format which allows the user to readily modify input variables and to make decisions on the various data reduction options. The reduced data are available for examination in easily interpretable format in a matter of minutes.

II. OVERVIEW AND PROGRAM CAPABILITIES

The program capabilities are outlined in the following section. In the form listed here it requires as input a suitable data file of pressure vs time and first derivative of pressure with respect to time and a "header" or set of parameters describing propellant geometry and physical characteristics, propellant thermochemistry and experimental parameters.*

A listing of the input requirements is contained in Appendix A, program operation is interactive and is controlled from a terminal keyboard. Two modes of operation are possible, standard and nonstandard. The standard option provides a "normal" burning rate analysis on a more or less routine basis. This analysis assumes full burning of all of the ignition aid before ignition of the propellant, simultaneous ignition of all the propellant grains, a fixed set of dimensions for all propellant grains, constant thermochemistry for the combustion products, and linear heat loss during the combustion of the propellant sample.

The second, nonstandard, mode of operation allows for operation of the program with a variety of options for special applications. A summary comparison of the "standard" and "nonstandard" modes of analysis is presented in Table I.

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* *The data file is obtained by operating on the range data with a smoothing and differentiation program "SCHECK." The program and operations are to be described in a future report.*

Table I. Comparison of Standard and Nonstandard Data Reduction Modes

FACILITY	STANDARD MODE	OPTION NO.	NONSTANDARD MODE
Heat Loss	Constant heat loss rate throughout burning	1	Compute heat loss based on convective and radiative heat transfer coefficients.
Thermochemistry	Average values of impetus, covolume, molecular weight, and γ used.	2	Thermodynamic data input as table (function of pressure).
Propellant Geometry	Fixed web used in calculations	3	Statistical treatment of web deviations used in calculations
Ignition	Simultaneous ignition of whole propellant charge.	4	Allows definition of ignition deviation in terms of time to account for flame spread effects.
Ignition Aid	All ignition aid burned before propellant ignited.	5	Propellant ignited before all of ignition aid is consumed.
Vented Vessel	No provision.	6	Allows computation of mass discharge when pressure exceeds diaphragm burst pressure.
Burning Surface	Capabilities provided: sphere; cylinder; and single, seven, and nineteen-perforated cylinders.	7	Allows input of any surface area function in tabular form.

Use of the program in either the standard or nonstandard mode has been simplified by allowing the use of propellant, igniter, and experimental data all from the same input file. Data on propellant geometry, thermochemistry, and dimensions are all recorded as "header" information at the time that the data are taken. (This is achieved using a separate program, CBDAP, closed bomb data acquisition program. The program will be described in another report.) The result is that conversion of the pressure-time data to linear burning rates may be performed simply without detailed knowledge of program operations. In performing a standard analysis, once the operator has entered the input data file, he is freed from providing any additional input except for specifying whether only the central portion (from 10 to 80 percent of maximum pressure) or all of the curve is to be plotted.

If changes are to be made in some of the propellant or igniter data or if special handling of the data is required, the nonstandard mode of analysis is employed. In this mode, the pertinent propellant and igniter data in the data file are displayed and the opportunity for changing or accepting the respective value is presented. In addition, the opportunity of selecting each of the options in Table I is presented to the user. Once these decisions have been made, data reduction proceeds as before.

Program output consists of: (a) a summary sheet or header describing the sample, experimental parameters and data on the maximum pressure and selected values of the derivative of pressure with respect to time (dP/dt), (b) a tabular listing of pressure, time, dP/dt, burning rate, web and surface fraction data, (c) superimposed plots of pressure (P) versus time (t) and dP/dt versus t. (d) a plot of dP/dt versus reduced pressure (P/P_{max}), and (e) a log-log plot of burning rate as a function of pressure. The burning rate versus pressure plot includes a printout of the coefficient and the exponent in the equation

$$r = AP^n \quad , \tag{1}$$

where: r = linear burning rate,

P = pressure,

A = burning rate coefficient, and

n = burning rate exponent.

obtained by a least squares fit of the data over the desired pressure range as well as statistical data on the "goodness of fit." An example of program output is given in Appendix B.

III. THEORY

A. SIMPLIFIED DERIVATION

The basic objective of the analysis is to derive linear burning rate data for propellant samples from pressure-time histories of their burning process in a closed bomb. Simply, the event involves the conversion of a solid sample composed of a large number of grains of a given geometry and size to a gas having a given amount of energy. Since the vessel is closed, the products may not escape, the pressure builds up and the propellant sample burns in an environment of a continuously changing pressure.

A variety of factors influence the conversion rate of the solid sample to gas. Those of primary interest are the propellant surface area, the pressure, and the propellant chemical composition. For all propellants, the conversion rate of solids to gas (i.e., the mass burning rate) is directly proportional to surface. For all gun propellants (and many others) the rate of regression of the propellant surface (the so-called linear burning rate, r) is directly proportional to pressure. As a general rule, the linear burning rates of propellants at given pressures are a function of the energy content of the composition.

To describe the process it is necessary to describe the gas produced, the unburned propellant and the energy balance for the process as a function of time. The derivation which follows is limited to a single propellant of constant thermochemistry. Eliminating complicating factors such as the presence of the igniter, ignition aid, etc., allows the generation of a simple instructive set of equations demonstrating the logic used. The actual equations used in the program are discussed in a later section and their derivation is given in the appendix.

(1) Equation of State of Gas

The combustion products may be described using the following equation of state:

$$PV_s = w_p R_s T_s \qquad (2)$$

where:

V_s = system volume

w_p = weight of propellant burned

R_s = gas constant for the system

T_s = gas temperature in the chamber

The equation is formally analogous to the familiar Ideal Gas Equation. The difference is in the definition of the system volume term (V_s) which is defined as the chamber volume modified to reflect the presence of unburned propellant and the covolume correction, Equation (3)

$$V_s = V_b - \frac{c_p}{\rho} + \frac{w_p}{\rho} - w_p\eta \qquad (3)$$

where:

V_b = chamber volume

c_p = initial weight of propellant

ρ = solid propellant density

η = propellant covolume.

It should be noted that the mixture of gases making up the propellant combustion products is treated as if it were a single gaseous species having specific properties of molecular weight, heat capacity and covolume. These properties, of course, are determined by the nature and stoichiometry of the combustion products.

Once the appropriate substitutions are made, the Equation of State becomes:

$$P\left[V_b - \frac{c_p}{\rho} + w_p\left(\frac{1}{\rho} - \eta\right)\right] = w_p R_s T_s \qquad (4)$$

(2) Energy Balance Equation

The energy from combustion of the propellant sample is partitioned between the internal energy of the product gases and heat loss to the chamber. The Energy Balance Equation may be written as:

$$E_{cv} = E_p - H_L \quad , \qquad (5)$$

where: E_{cv} = energy of gases in the chamber

E_p = energy from combustion of the propellant, and

H_L = heat loss to walls of the chamber

The equation may be rewritten as:

$$C_V w_p T_s = C_V w_p T_{0p} - H_L \tag{6}$$

where: C_V = heat capacity at constant volume and

T_{0p} = isochoric flame temperature of propellant.

$$H_L = \frac{C_V V_s}{R_s} (P_{0s} - P_m)$$

P_{0s} = Theoretically computed maximum pressure

P_m = Experimentally measured maximum pressure

The temperature of the combustion gases, T_s, is less than the isochoric adiabatic flame temperature computed for the propellant composition, T_{0p}, due to heat losses to the walls of the chamber. The heat capacity at constant volume, C_V, is an average property between T_s and T_{0p} for the mixture of gases making up the combustion products of the formulation. It is defined per unit weight, rather than per mole.

(3) Rate of Conversion of Solid to Gas.

To obtain the equation for the rate of conversion of the solid propellant to gaseous combustion products, Equations (4) and (6) are differentiated. Differentiation of Equation (4) holding V_b, c_p, ρ, η and R_s constant, yields:

$$\left[V_b - \frac{c_p}{\rho} + w_p \left(\frac{1}{\rho} - \eta\right)\right] \frac{dP}{dt} + P \left(\frac{1}{\rho} - \eta\right) \frac{dw_p}{dt} = R_s w_p \frac{dT_s}{dt} + R_s T_s \frac{dw_p}{dt} \tag{7}$$

The rate of conversion of solid to gas is given by dwp/dt, the rate of formation of propellant combustion products. This is the term we are seeking to evaluate in terms of experimental parameters. To do this, it is necessary to define the rate of change of system temperature

(dT_s/dt). This is done by differenting the Energy Equation. Differentiation of Equation (6) holding C_V and T_{0p} constant and rearranging, yields:

$$\frac{dT_s}{dt} = \frac{(T_{0p} - T_s)}{w_p} \frac{dw_p}{dt} - \frac{\dot{H}_L}{C_V w_p} \tag{8}$$

at this point, the following relationship is introduced:

$$R_s = C_V (\gamma - 1)$$

where:

γ = ratio of heat capacities

The relationship is strictly true for ideal gases but is commonly used in describing real systems. It allows recasting Equation (8) in the following form:

$$\frac{dT_s}{dt} = \frac{(T_{0p} - T_s)}{w_p} \frac{dw_p}{dt} - \frac{\dot{H}_L (\gamma-1)}{R_s w_p} \tag{9}$$

Substituting the right hand side of Equation (9) into the differentiated Equation of State, Equation (7); yields:

$$\left[V_b - \frac{c_p}{\rho} + w_p \frac{(1 - \eta)}{\rho}\right] \frac{dP}{dt} = \left[R_s T_s - P \frac{(1 - \eta)}{\rho}\right] \frac{dw_p}{dt} + R_s w_p \left[\frac{(T_{0p} - T_s)}{w_p} \frac{dw_p}{dt} - \frac{\dot{H}_L (\gamma-1)}{R_s w_p}\right] \tag{10}$$

The equation may now be solved for dw_p/dt, giving the rate of formation of propellant combustion products in terms of experimental data (P, dP/dt) and a series of constants (V_b, c_p, ρ, η, T_{0p}, R_s, $\dot{H}_L$ and γ). The resulting equation is:

$$\frac{dw_p}{dt} = \frac{\left[V_b - \frac{c_p}{\rho} + w_p \frac{(1}{\rho} - \eta)\right] \frac{dP}{dt} + \dot{H}_L (\gamma-1)}{R_s T_{0p} - P \left(\frac{1}{\rho} - \eta\right)} \tag{11}$$

(4) Linear Burning Rate.

The linear burning rate, r, is the rate of regression of the propellant surface (dx/dt). To compute it one begins with considering the volume element burned through during an infinitesimal time interval. The following equation applies:

$$\frac{dw_p}{dt} = \rho S_t \frac{dx}{dt} \tag{12}$$

where:

S_t = the surface area of the propellant at any time t.

$\frac{dx}{dt}$ = rate of regression of the propellant surface, equals r, the linear burning rate.

Equation (12) defines the rate of formation of propellant combustion products in geometric terms. If the propellant is composed of a number of identical grains, the propellant surface area may be computed using a variety of "form function" equations. Equations have been developed for spherical, cylindrical and perforated cylindrical (1, 7, and 19 perforations) grain geometries. The generalized equation is:

$$S_t = f(x) \tag{13}$$

where:

x = the distance burned into the grain.

When x equals zero, the surface area is the initial surface area of the propellant grain. As x increases positively, the surface area of the grain changes characteristically for each grain type. Form functions for all of the grain types mentioned above have been included in Appendix C.

Examining Equation (12), it is evident that the objective of computing the linear burning rate of the propellant from the closed bomb pressure-time data has been attained. The term dw_p/dt is defined by Equation (11), and the surface area, S_t, is defined by the Form Function Equation, Equation (13). This completes the simplified derivation intended for inclusion in the text.

B. Theory Used in The Program.

Both the event described and the equations describing it are considerably more complex than just described. In every experiment an igniter is used to start the propellant burning and in many an ignition aid is used as well. Further, the volume in the bomb not occupied by the propellant at the start of the experiment is occupied by ambient air. It is, therefore, evident that one is not dealing with the single component system described earlier. The Equation of State used in the program includes all components. The Energy Equation is also more complex, since the thermodynamics of the combustion gases are allowed to change and, in addition, allowance is made not only for heat loss from the system but mass loss as well (vented chamber operation). The Mass Burning Rate Equation derived for the system reflects these complexities. See Equation (27), Appendix D. Since the treatment allows for deviations in the ignition of the propellant charge as well as web deviations, computing the surface area at any instant is also slightly more complicated. Finally, the instantaneous Heat Loss Term ($\dot{H}_L$) is evaluated in the program in one of two ways, either as an average value, constant throughout the burn, or as a variable defined by the radiative and convective heat loss elements. The objective of this section is to provide some explanatory comments on several equations used in the program.

(1) Rate of Conversion of Solid to Gas.

For the purpose of discussion the Mass Burning Rate Equation derived in Appendix D has been regrouped and the numerator divided into a series of terms A through E. This is the form in which it appears below.

$$\frac{dw_p}{dt} = \frac{A + B + C + D + E}{P(\eta - \frac{1}{\rho}) + T_{0p}R_s + R_u T_s \left(\frac{1}{\bar{M}_p} - \frac{1}{\bar{M}_s}\right)} \tag{14}$$

where:

R_u = universal gas constant

M_p = molecular weight of propellant combustion products

M_s = molecular weight of gas in the system

$$A = V_s \frac{dP}{dt}$$

$$B = \dot{H}_L (\gamma - 1)$$

$$C = \left[\gamma R_s T_s + P\eta \frac{w_{p1}}{w_s} \right] \frac{dw_n}{dt}$$

where:

w_{p1} = weight of propellant combustion products in the chamber (as opposed to the total weight of propellant burned)

$\frac{dw_n}{dt}$ = gas discharge rate through the nozzle

$$D = w_s T_s \left[\frac{R_u}{(M_p)^2} \frac{dM_p}{dt} + \frac{R_s}{C_V} \frac{dC_V}{dt} \right] - P w_s \frac{d\eta}{dt}$$

$$E = - \left[P(\eta - \frac{1}{\rho}) + T_{0a} R_s + R_u T_s (\frac{1}{M_a} - \frac{1}{M_s}) \right] \frac{d w_{a1}}{dt}$$

where:

M_a = molecular weight of ignition aid combustion products

w_{a1} = weight of ignition aid combustion products in the chamber.

Several of the terms are associated with exercising program options previously described (Table I). The functions of Terms A through E are listed in Table II.

Table II. Functions of Terms A through E in Equation (14).

A	System volume term
B	Heat Loss.
C	Mass Loss.
D	Variable thermochemistry.
E	Contribution of simultaneously burning ignition aid.

The System Volume Term (A) is necessary for all computations. The Heat Loss Term (B) is included as required in the analysis. The term may be evaluated simply (standard option, Table 1) or comprehensively (nonstandard option). This will be discussed more fully in section B(3). In the case of vented chamber operation or in computing burn rates from artificially generated pressure time data, term B can be zero. The Mass Discharge Term, (C) is used in analyzing vented chamber experiments. Term (D), Variable Thermochemistry, is important in analyzing low pressure closed bomb data since the thermochemistry of the combustion products changes significantly with pressure at low pressures. The inclusion of the Ignition Aid Burning Term (E) becomes important when describing situations involving simultaneous burning of propellant and igniter. This is the case more often than not, though the decision on the overlap of ignition aid and propellant burning is made on the basis of experience by the program operator.

In essence, Equation (14) is Equation (11) appropriately modified to reflect the complexities of the experiment. This may be readily demonstrated by imposing the same assumptions on Equation (14) as were used in deriving the simplified Mass Burning Rate Equation (Equation 11). Assuming a single propellant (no igniter or ignition aid), constant thermochemistry, closed bomb operation (no mass loss through a nozzle) and the absence of air from the chamber, the following terms in Equation (14) may be eliminated:

Term C. Under closed bomb conditions $dw_n/dt=0$

Term D. For constant thermochemistry $d\eta/dt=0$

Term E. In the absence of an ignition aid $dw_{ai}/dt=0$

$\left[R_u T_s \left(\frac{1}{M_p} - \frac{1}{M_s}\right)\right]$. For a single component system $(1/M_p - 1/M_s) = 0$

Elimination of the terms above reduces Equation (14) to Equation (11). The methods used in deriving the two equations were the same. The derivation of Equation (14) paralleling the approach used in the text for Equation (11) is given in Appendix D.

(2) Linear Burning Rate

The linear burning rate in the program is computed by Equation (12). Differences arise, however, in the computation of the instantaneous burning surface area S_t. Two of the program options treat ignition deviations in the propellant charge and web deviation in the propellant grains. Both options influence the burning surface area.

If an ignition deviation takes place, parts of the propellant charge begin to burn before others. In this case the simple computation of total burning surface area as a function of distance burned is not appropriate. What is done is to proportion the propellant charge into five parts (two each of 10 percent, two each of 20 percent and one of 40 percent) and to allow the ignition of the charge increments to differ by some arbitrary time input by the operator. The distances burned into the surface of each portion of the charge are carried separately. Under these conditions the burning surface is computed according to the following equation:

$$S_t = \Sigma_1^5 \; S_{t_n} \tag{15}$$

where:

S_{t_n} = surface area of the nth propellant charge increment

S_{t_n} = $f(x_n)$

x_n = distance burned into the surface of the nth propellant charge increment.

Of course, for simultaneous ignition of the propellant charge, Equation (15) reduces to Equation (13). It must be emphasized, however, that one has no a priori knowledge of the ignition deviation time of the propellant charge; so this treatment should be viewed with caution.

The web deviation is handled analogously; In this case, however, web deviation values may be obtained from actual measurements.

(3) Heat Loss

(a) Standard Option. Evaluation of the Heat Loss Term ($\dot{H}_L$) is done in either of two ways. In the standard option it is some suitable average value, constant throughout the analysis. The following equation applies:

$$\dot{H}_L = \bar{\dot{H}}_L = \frac{C_V V_s}{R_s} \frac{(P_{0s} - P_m)}{\left(t_{pm} - t_{ig}\right)} \tag{16}$$

where:

$\bar{\dot{H}}_L$ = average heat loss rate

P_{0s} = theoretically computed maximum pressure (adiabatic conditions, contributions from propellant, igniter, ignition aid and air in system).

t_{pm} = time of maximum pressure

t_{ig} = time of ignition

The total heat loss is the difference between the adiabatically computed internal energy of the system and the internal energy computed from the maximum pressure observed. The total heat loss is converted into the average Heat Loss Rate ($\bar{\dot{H}}_L$) by dividing by the burning time interval (t_{pm}-t_{ig}).

(b) Nonstandard Option

In the nonstandard option, heat loss is analyzed into its convective and radiative components. It is assumed that during the time that the propellant burns the gas generation results in convective heat transfer to the chamber walls. This is, of course, accompanied by radiative heat losses as well. After the propellant is consumed it is assumed that the convective heat loss becomes insignificant relative to the radiative heat loss. These assumptions allow the following treatment.

(i) Radiative heat loss coefficient. The temperature of the gases in the system is given by:

$$T_s = \frac{P_m V_s}{R_s}$$

The radiative heat loss rate is given by:

$$\dot{H}_{Lr} = \frac{C_V V_s}{R_s} \frac{dP}{dt} \tag{17}$$

where:

$\dot{H}_{Lr}$ = radiative heat loss rate,

Once a matched array of T_s, $\dot{H}_{Lr}$ data are generated, they may be fitted to the following relationship:

$$h_r A_w = \frac{\dot{H}_{Lr}}{(T_s^4 - T_w^4)} \tag{18}$$

where:

h_r = radiative heat transfer coefficient

A_w = bomb surface area

T_w = bomb wall temperature.

In carrying out these computations, T_w^4 may be neglected since it is indeed insignificant ($T_s^4 >> T_w^4$) in the radiant heat transfer. The bomb surface area (A_w) is one of the program inputs (alternately a default value of 18.1 in^2 is available in the program) and, therefore, the evaluation of the Radiant Heat Transfer Coefficient (h_r) is accomplished. Throughout the analysis, h_r is a constant.

(ii) Convective Heat Transfer Coefficient. The Convective Heat Transfer Coefficient (h_c) is assumed to be a function of the instantaneous mass flow as in the case of heat transfer in a pipe. The relationship is given as:

$$h_c = F_c \left(\frac{dw_s}{dt}\right)^{0.8} \tag{19}$$

where:

h_c = convective heat transfer coefficient

F_c = proportionality constant

The value of h_c is computed at every point in the analysis using the instantaneous mass generation rate. The value of the proportionality constant F_c is obtained using an approximation technique in which an approximate value of h_c is calculated from the average mass generation and heat loss rates and this approximate value is refined using the value of h_r and increments of $\Delta P/\Delta t$.

(iii) Heat Loss Rate, nonstandard option. To compute the Heat Loss Rate ($\dot{H}_L$) at any given point in the analysis the following equations are used:

$$\dot{H}_{Lc} = h_c A_w (T_s - T_w) \tag{20}$$

where: $\dot{H}_{Lc}$ = convective heat loss rate

$$\dot{H}_{Lr} = h_r A_w (T_s^4 - T_w^4) \tag{21}$$

$$\dot{H}_L = \dot{H}_{Lc} + \dot{H}_{Lr} \tag{22}$$

The initial value of the Wall Temperature (T_w) is assumed to be 450°K (this may be changed by the operator) and T_w is continuously adjusted throughout the analysis as is the Systems Temperature (T_s). The relationships governing heat conduction to the wall are given in Appendix E.

IV. PROGRAM STRUCTURE AND OPERATION

A. Standard Analysis

The program consists of a main program and a number of subroutines which handle reading in of data, unit conversions, heat loss computations, burning rate calculations, and printing and plotting of the output data. The program structure is outlined in Figure 1. The diagram indicates the relationship of the subroutines in the program. Capsule summaries of the functions of the subroutines are contained in Appendix F.

Program operation is most easily described by following a standard analysis sequence step by step. The options may then be seen as perturbations on the normal mode of analysis. A flow diagram of the program appears in Figure 2. The chart has been arranged to show the operations involved in a standard analysis in sequential form. The options possible, heat loss, mass loss, variable thermochemistry, etc., are shown offset from the main sequence of operations. The optional sections are marked with arterisks.

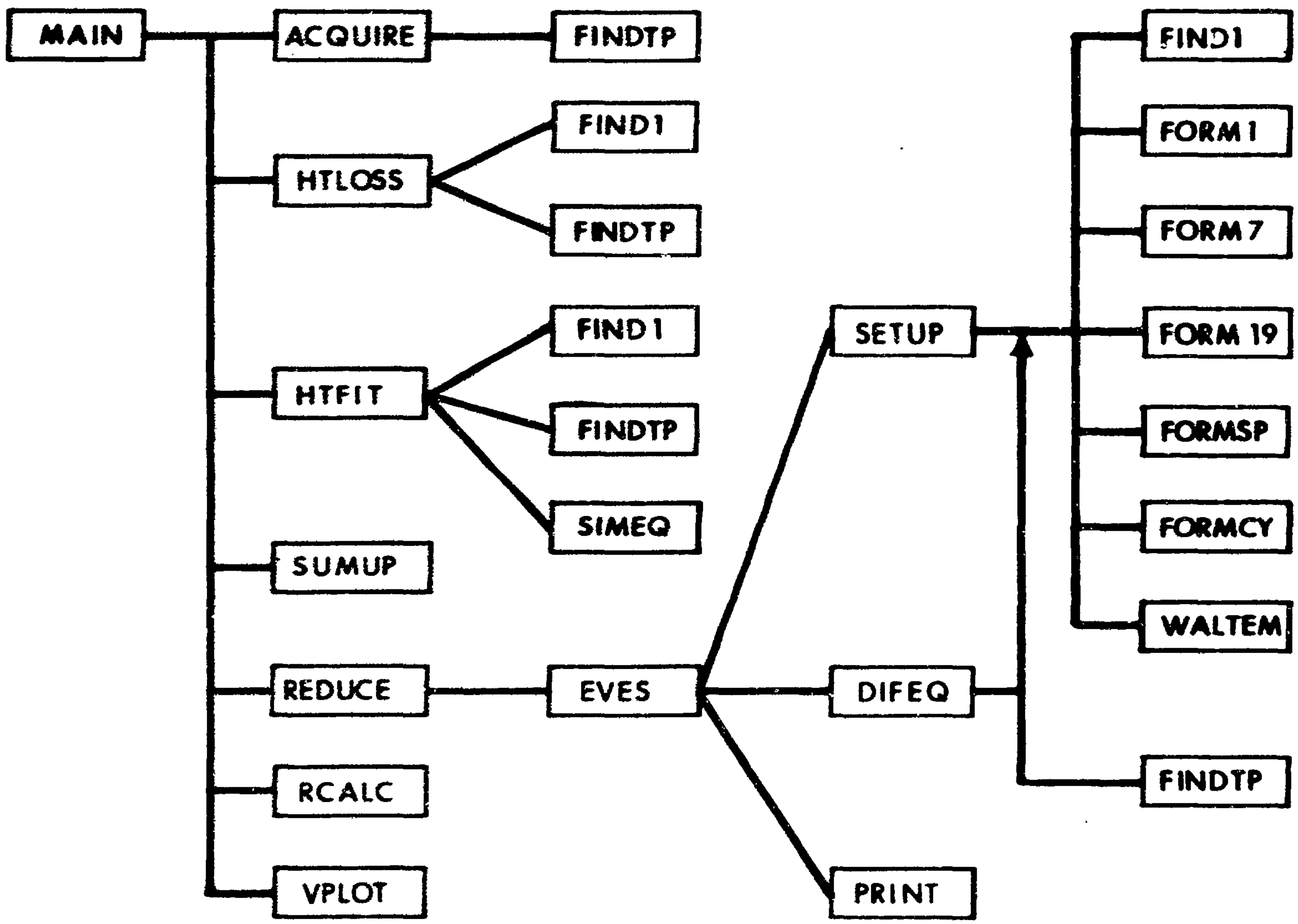

Figure 1. Program Structure (CBRED). Interrelation of Subroutines.

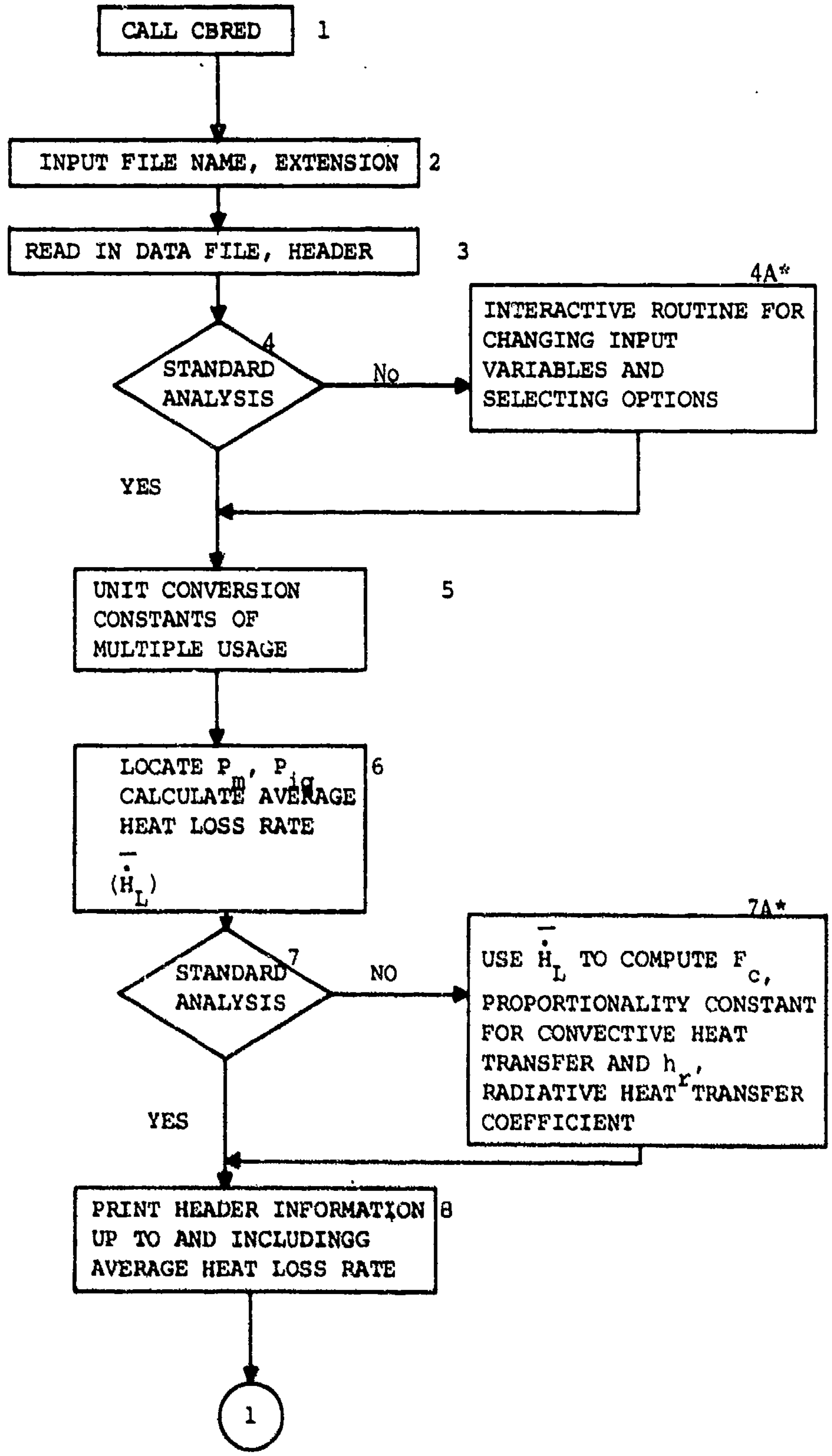

Figure 2-1. Closed Bomb Burn Rate Program (CBRED). Generalized Flow Scheme.

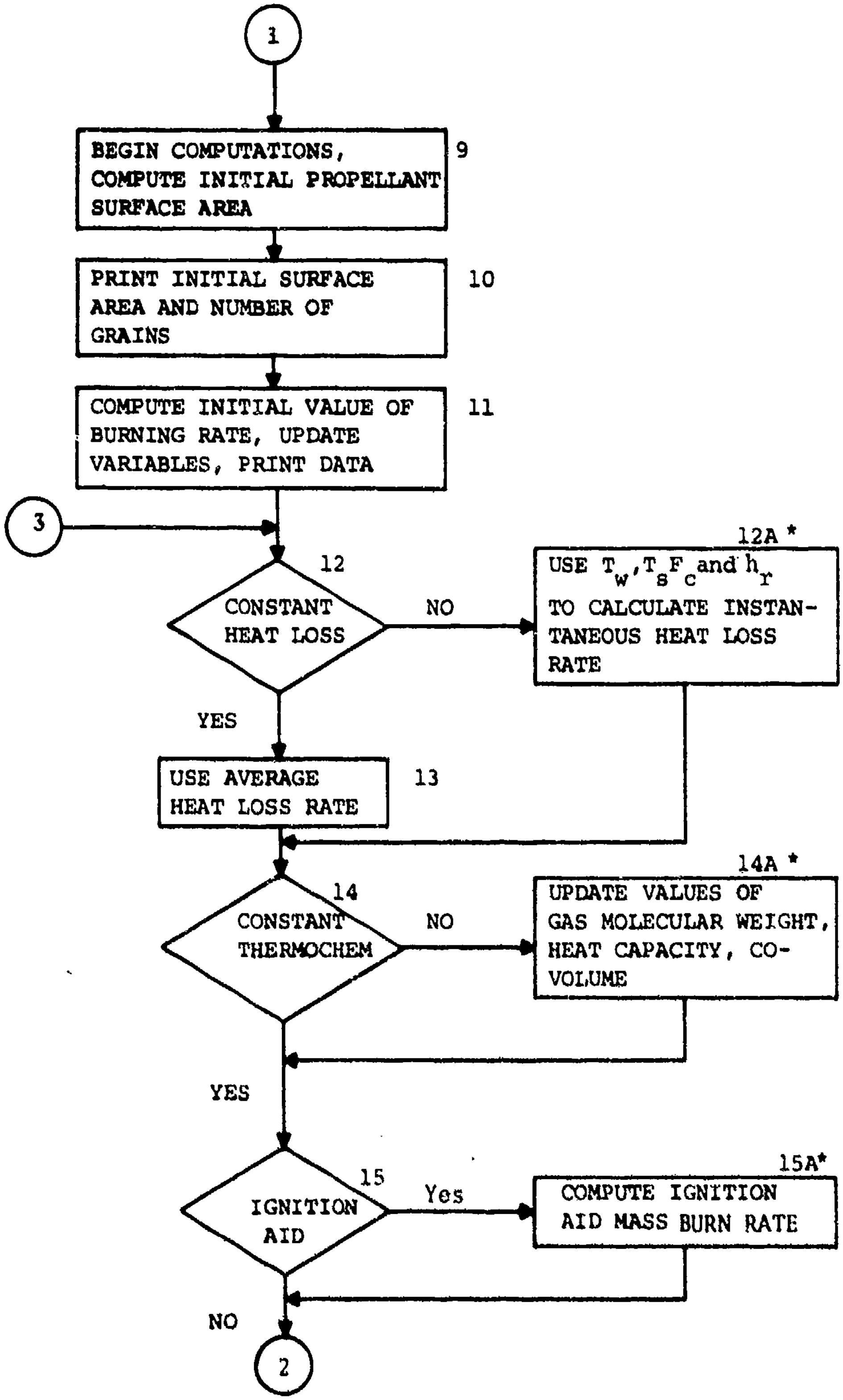

Figure 2-2. Closed Bomb Burn Rate Program (CBRED). Generalized Flow Scheme

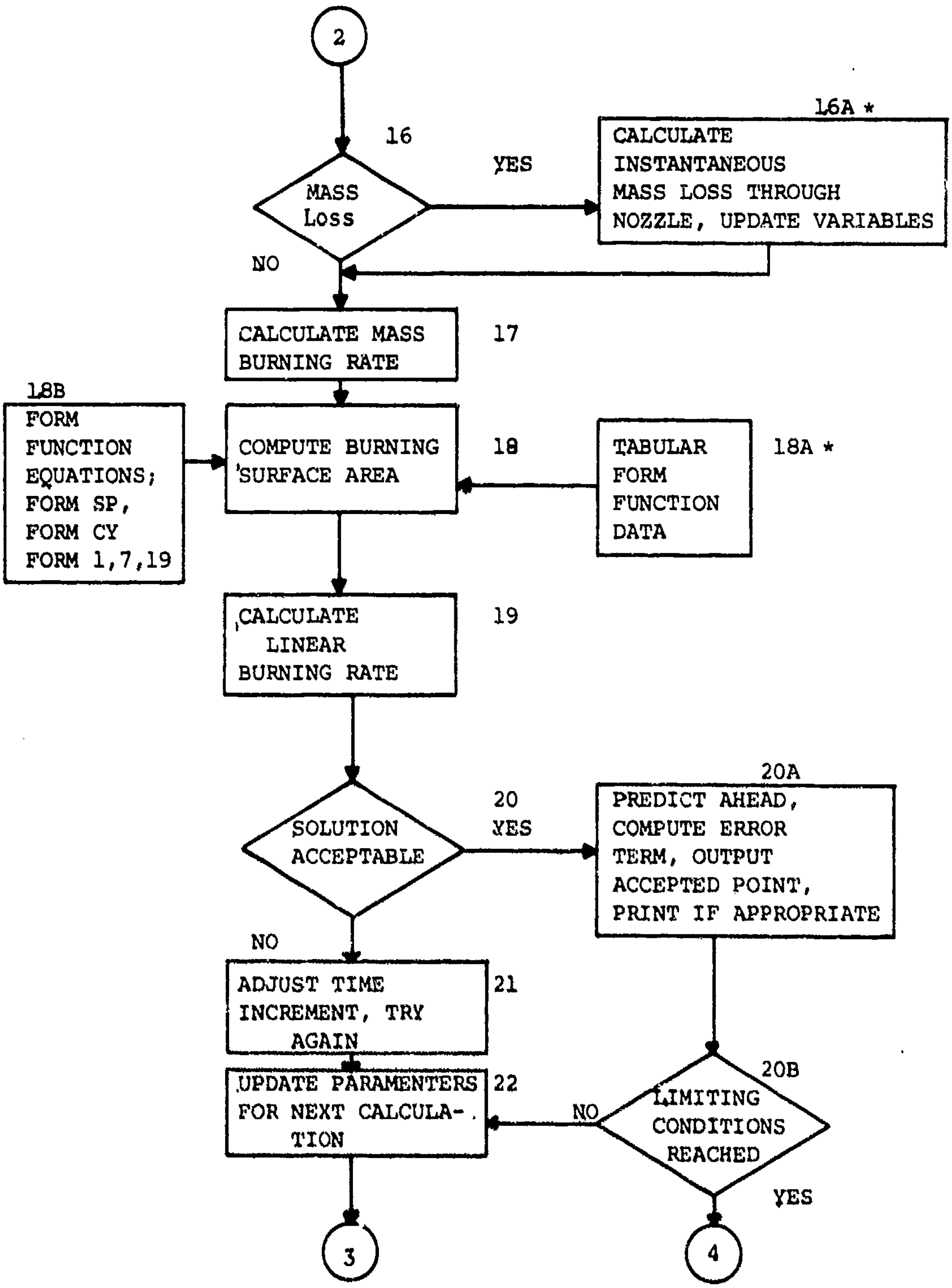

Figure 2-3. Closed Bomb Burn Rate Program (CBRED).
Generalized Flow Scheme.

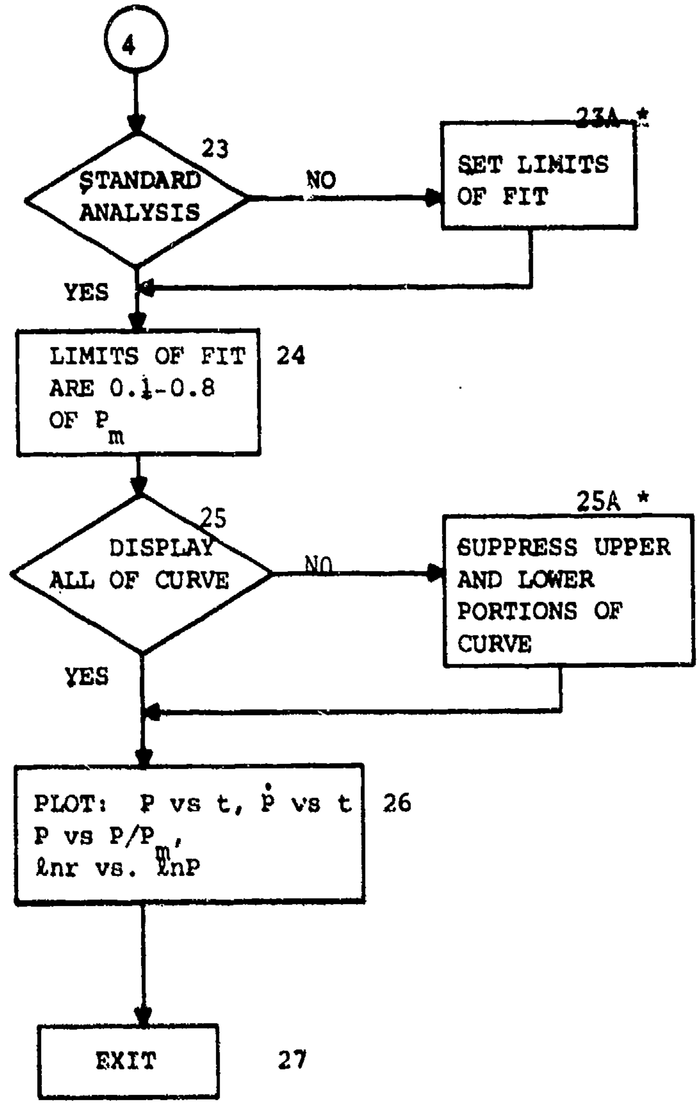

Figure 2-4. Closed Bomb Burn Rate Program (CBRED).
Generalized Flow Scheme.

1. Start up (Blocks 1, 2 and 3). Once the program (CBRED) is called, it signs in and requests the file name and extension of the data file to be analyzed. On input of the file name and extension the data file is read in. The input data consists of matched arrays of pressure-time and time derivative of pressure-time data as well as a data set consisting of experimental, thermodynamic and grain geometry data (see Appendix A). The data is stored on magnetic tape and is handled as a single unit. (At the time the experiments run, the operator records in the data file all the parameters required for data reduction. This is done using a separate program, CBDAP. The pressure-time data obtained is differentiated by a second program, SCHECK. The "header" information is carried through to the new data file. Opportunities for updating the "header" information are provided by both programs). These operations take place in the main program and subroutine ACQUIRE.

2. Mode of Analysis (Block 4). The question is posed to the operator whether the analysis to be performed will be in the standard or nonstandard mode. Once the choice for the standard analysis mode has been made, the program goes into execution without further input from the operator. See subroutine ACQUIRE also.

3. Initialization (Block 5). At this point a variety of operations necessary to initialize the problem are performed. The input parameters are converted to a consistent set of units. At present a pound, foot (inch), second, BTU system is employed, but gas temperatures are in degrees Kelvin. A number of constants of multiple usage are also computed. This also takes place in subroutine ACQUIRE. On completion of this task, control reverts to MAIN which then passes operations to subroutine HTLOSS.

4. Heat loss (Block 6). At this point the input data file is searched for the maximum pressure, the maximum time derivative of pressure and selected values of P and dP/dt. The ignition pressure is computed using the igniter weight and thermochemistry and the theoretical (adiabatic) maximum pressure is calculated. This data is used to compute the Average Heat Loss Rate ($\bar{\dot{H}}_L$). Other operations including setting the ignition time for the analysis, setting the starting time interval, computing the initial system temperature and gas generation rate are also performed. These operations are performed in subroutine HTLOSS. Control then passes to MAIN which relinquishes operation to subroutine SUMUP.

5. Run header (Block 8). The function of subroutine SUMUP is to provide the identifying information for the run. Information on the data file designation, propellant parameters, igniter data, bomb data as well as summary information on the pressures and the time derivatives of pressure obtained are printed. The first page and part of the second page of Appendix B are the output from this operation. The only portion of the header not printed at this point relates to the initial

propellant surface area and the number of propellant grains. Subroutine SUMUP passes control back to MAIN which then passes control to subroutine REDUCE.

6. Begin Computation (Blocks 9-11). Subroutine REDUCE controls the differential equation solver, subroutine EVES. It specifies the number of differential equations to be solved, the stopping time and the interval at which data are to be printed out. (See pages 3 and 4 of Appendix B). Control then passes from REDUCE to EVES until the stopping time (or some other limiting condition) is reached.

To initiate computations, subroutine EVES calls subroutine SETUP whose job it is to provide the initial values of the functions and the factors needed to calculate the starting values of the differentials. Values are assigned to the propellant mass generation rate, ignition aid burning rate, mass loss rate, thermodynamic parameters, heat loss, etc. In a standard analysis, the initial heat loss rate is the average heat loss rate computed earlier in subroutine HTLOSS. The initial mass loss rate and igniter burning rate are zero. The initial surface area of the propellant is computed by calling the appropriate form function subroutine. The surface area data and the number of propellant grains are then printed, completing the "header" section of the program output (Block 10). Control passes from SETUP through EVES to DIFEQ where the initial values of the differentials are computed. (The functions evaluated using DIFEQ and EVES are designated as Y(N) and their differentials as DY(N); see the FORTRAN column in the List of Symbols.) In a standard analysis, the initial mass burning rate is set equal to the ignition aid mass burning rate at the point of ignition. The other mass differentials (and their integrals) are, of course, zero.

Using the starting values of the function (Y_0) and its differential ($\dot{Y}_0$) EVES computes an estimated value for the function at the completion of the first time interval ($\bar{Y}_1$). This value is fed back to DIFEQ where it is used to obtain a new value of the differential ($\dot{Y}_1$). The difference between ($\dot{Y}_0$) and ($\dot{Y}_1$) is examined and compared with an error level built into the program. If the value passes, the value of the function (Y_1) and its differential ($\dot{Y}_1$) are accepted, the time interval is incremented (Block 9) and the process is repeated. The initial integration steps are purposely kept small to establish the initial table of differences required by the predictor-corrector technique. Subroutine EVES has the built in capability to adjust the size of the time step used as the analysis progresses so that under conditions where the predictor values are better than required by the difference critereon, the time steps are increased in size, providing a savings of computation time. Time steps are, of course, also automatically reduced by the program as required.

7. Compute Burning Rates (Blocks 12 through 22). The process just described is followed to obtain the required values of linear burning rates throughout the analysis. At each step where a new value of (dw_p/dt) is required, subroutine DIFEQ computes the values based on the updated values of the parameters in the Mass Burning Rate Equation. The value is examined in EVES and accepted or rejected as necessary. Blocks 12 through 22 are involved in the process; Of these 12 through 19 take place in subroutine DIFEQ and the appropriate form function subroutine. In a standard analysis the heat loss rate is constant and the average heat loss rate is used. Since propellant thermodynamic characteristics are constant, no updating of values is done. The same is true for both the ignition aid burning and the mass loss terms. If the solution of the differential equation (as judged in EVES) is acceptable at any point, values for burning rate are accepted along with those of w_p and dw_p/dt. At given intervals during the analysis the data are printed out (EVES calls subroutine PRINT), see pages 50 and 51 of Appendix B. Tests for limiting conditions (web, all burned, pressure = P_m, and time = T_m) are made throughout the analysis and once one of the limiting conditions is reached, EVES returns control to REDUCE which returns control to MAIN.

8. Fitting the burning rate data (Block 25). Once the reduction phase is completed, the burning rate data between 0.1-0.8 of P_m is fitted to an equation of the form $r=AP^n$. This is done in subroutine RCALC.

9. Plotting of data and results. (25,26). The question is posed to the operator whether the lower and upper portion of the burning rate curve are to be suppressed. Generally this is done, since the most meaningful data is between 0.1 & 0.8 of P_m. After this decision, P vs.t; dP/dt vs t; dP/dt vs P/P_m and ℓnr vs. ℓnP^m are prepared and the program exits. The complete output package from the program may be seen in Appendix B.

B. Nonstandard Analysis

If the nonstandard mode of analysis is chosen, an interactive display is activated in subroutine ACQUIRE (Block (4A) which allows temporary modification of the pertinent ballistic information appearing in the data file. In addition to these changes, decisions concerning a variety of options have to be made. A brief discussion of each of the options, follows.

1. Heat loss. (Blocks 7A, 12 and 12A). In the nonstandard mode, the first option concerns the assignment of heat loss. The standard option, (Block 6). was described earlier. The nonstandard option (Block 7A) is a much more sophisticated treatment which assigns values to the convective and radiative components of heat loss based on the decay portion (after P_m) of the firing record itself. The theory was discussed earlier. In the reduction phase of the program

the heat loss rate ($\dot{H}_L$) is computed at each point in subroutine DIFEQ. Both the convective and radiative heat loss rates are functions of the gas and wall temperatures. Subroutine WALTEM is, therefore, invoked to provide current values of wall temperature as are needed in the analysis. This is shown schematically by Block 12A in Figure 2.

2. Propellant Geometry (Blocks 18A & 18B). The purpose of this option is to approximate the effect of real propellant geometry by using a distribution of web values rather than nominal web values. The computations take place in DIFEQ and the appropriate form function subroutine. A web deviation value may be input in the nonstandard mode resulting in the proportioning of the propellant charge into five parts: two each of 10 percent, two each of 20 percent, and one each of 40 percent of the total charge with webs differing from the nominal by plus or minus suitable factors times the web deviation derived from a normal population distribution curve. These five propellants, equivalent in weight to but not having the same initial area or the same overall form function as the total charge considered as a nominal case are treated as separate entities in the burning area portion of the reduction and the instantaneous areas summed for calculation of the linear burning rate. This option eliminates sharp discontinuities of surface area at certain points. (Computer generated pressure-time curves using this approach have resulted in much closer agreement with dP/dt data taken from real propellant geometries.) Only the burning area portion of the analysis is affected.

3. Ignition Deviation. This option permits the simulation of flame spreading effects that may occur in an experimental firing. A population distribution similar to the one above (propellant geometry section) is used. The propellant is assumed to be composed of five samples, each ignited at a different time. (It is the value of the time interval that is input from the keyboard.) The distance burned for each fraction is calculated separately. These values of x are used to compute the area of the burning surface of the charge during the analysis. A linear interpolation method is used to remove gross discontinuities in the burning area between the times of ignition of two adjacent samples and upon burnout of the first sample. Only the burning area portion of the program is affected by this option. Operations take place in subroutine DIFEQ which calls the appropriate form function subroutine as required.

4. Ignition Aid. (Block 15, 15A). This option is useful in describing situations in which not only an igniter but also an ignition aid is present. Since the ignition aid actually has a finite burn time relative to the propellant, the option allows modification of the "ignition pressure" to account for the partial burnout of the aid material at the time that propellant ignition takes place. During the early phase of the firing, therefore, both propellant and ignition aid will be contributing to the mass generation rate, hence to dP/dt. The aid contribution must be evaluated separately. At present this is

accomplished by external input or by analysis of the dP/dt portion of the record just prior to the chosen ignition point (pressure), translating this dP/dt into an equivalent mass burning rate of the aid and fitting it to a power law curve. Evaluation of the instantaneous value of the ignition aid burning rate is performed in subroutine DIFEQ. The function is integrated in EVES. The computation of the mass burning rate (Block 17) is, of course, affected (see Equation 14 term E).

5. Variable thermochemistry. (Blocks 14 and 14A). This option allows the input of the required thermochemical information for the propellant in the form of a table of values versus pressure. The table entry takes place in subroutine ACQUIRE. Values for the rate of change of covolume, heat capacity etc. are computed in subroutine DIFEQ and used in calculating the mass burning rate of the propellant (also in DIFEQ).

6. Vented Chamber Operation. (Blocks 16 and 16A). This option allows analysis of firings made with "leaking" or vented vessels. The effective vent area and the blow-out pressure of the vent are necessary inputs and their presence will automatically result in analysis beyond the time of P_{max} and the computation of the mass-discharge term in the differential equations. Instantaneous temperatures as well as the effects of changing molecular weight are used in determining this term.

7. Burning Surface. (Block 18A). In this option, an arbitrary total burning surface area as a function of some characteristic burning dimension may be input to the program if none of the available form functions appear suitable. The input consists of a table of points, and the instantaneous area is interpolated linearly from the information furnished. For seldom used unique geometries, it avoids the nuisance of recompiling the program to include a special form function generator.

C. <u>Summary</u>

A versatile closed bomb data reduction program has been developed to compute linear burning rate of propellants from the pressure-time histories of their burning process. In Section II, the capability of the program as seen from the user's point of view was discussed, and a comparison of the standard and nonstandard modes of analysis was made. An introduction to the theoretical treatment was made in Section III and the relationship between the equations used in the program and the simplified derived equation was examined. In Section IV, program structure and operation were examined and a flow chart of the program as well as a diagram of the subroutine hierarachy was given. Finally, the impact of each of the options on program execution was discussed. The derivation of the mass burning equations (Appendix D) as well as a program listing (Appendix G) are provided.

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REFERENCES

1. J. Corner, M. A. PhD, Theory of the Interior Ballistics of Guns, New York, John Wiley and Sons, Inc., 1950.

2. Paul G. Baer and Jerome M. Frankle, "The Simulation of Interior Ballistic Performance of Guns by Digital Computer Program," Ballistic Research Laboratories Report No. 1183, December 1962, AD # 299980.

3. A. C. Haukland and W. M. Burnett, "Sensitivity of Interior Ballistic Performance to Propellant Thermochemical Parameters," Proceedings of the Tri-Service Gun Propellant Symposium, 11-13 October 1972, Picatinny Arsenal, Dover, NJ, Vol 1, Section 7.3.

4. Paul G. Baer, Ingo W. May, and Jerome M. Frankle, "A Comparison of Several Predictive Approaches in Charge Establishment for Large Caliber Artillery Systems," Proceedings of the 11th JANNAF Combustion Meeting, Jet Propulsion Laboratory, Pasadena, CA., September 1974, Vol 1; C.P.I.A. Publication 261, December 1974, The Chemical Propulsion Information Agency, Silver Spring, Md.

5. William H. Tschappat, Lt.-Col, Ord. Dept., Text-Book of Ordnance and Gunnery, 1st Ed., New York, John Wiley and Sons, Inc., 1917, pp. 111-118.

6. Albert A. Bennett, PhD, "Tables of Interior Ballistics," Ordnance Department Pamphlet No. 2039, April 1921.

7. D. W. Reifler and D. J. Lowery, "Linear Burn Rates of Ball Propellants Based on Closed Bomb Firings," Ballistic Research Laboratories Contractor Report No. 172, August 1974. (AD #921704L)

8. Henri Muraour, "Chemie Physique sur la Reaction Entre La Temperature de la Explosion d' une Poudre et sa Vitesse de Combostion," Comp. rend., Vol 187, 1928, pp. 289-294.

9. Ref 1, pp. 42-84 and references therein.

10. Bryce L. Crawford, Jr., Clayton Huggett, and J. J. McBrady, "The Mechanism of Burning of Double Base Propellants," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 854-862.

11. Robert G. Parr and Bryce L. Crawford, Jr., "A Physical Theory of Burning of Double Base Rocket Propellants," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 929-954.

12. O. K. Rice and Robert Ginell, "The Theory of Burning of Double Base Rocket Powders," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 885-917.

REFERENCES (Continued)

13. R. E. Wilfong, S. S. Penner, and F. Daniels, "An Hypothesis for Propellant Burning," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 863-872.

14. R. D. Geckler, "Mechanism of Combustion of Solid Propellants," Selected Combustion Problems, London, Butterworths Scientific Publications, 1954, pp. 289-339.

15. D. B. Spalding, "The Theory of Solid and Liquid Propellants," Combustion and Flame, Vol 4, 1960, pp. 59-76.

16. Method 801.1.1, "Quickness and Force Measurement of Propellant (Closed Bomb Method)," (Revised 21 Oct 75), Military Standard 286B, Department of Defense, Washington, DC 20301.

17. C. M. Dickey, "Determination of Burning Characteristics of Propellant," E. I. duPont de Nemours and Company, Explosives Department, Burnside Laboratory, Memorandum Report No. 31 (File BL-135-101), March 1943.

18. James H. Wiegand, "A Method of Calculation of the Burning Rate of Powders from dP/dt vs. P Records for Closed Chambers," Ballistic Research Laboratories Report No. 546, June 1945.

19. E. Haeuseler and W. Dehl, "State of Development of Testing Procedures for Propellants in the Closed Vessel," Explosivstoffe, Vol 18, 1970, pp. 41-52.

20. H. Krier and S. A. Shimpi, "Predicting Uniform Gun Interior Ballistics: - Part I - An Analysis of Closed-Bomb Testing," University of Illinois Technical Report AAE-74-5, July 1974 (Contract DAAA-21-73-C-0549).

Selected Bibliography of Closed Bomb Burn Rate Reduction Methods

1. Bonner, L.G., "Determination of the Linear Burning Rates of Propellants from Pressure Measurements in the Closed Chamber," OSRD Report No. 4382, Office of Scientific Research and Development, Washington, D. C., 1 November 1944.

2. Celmins, A., "Solid Propellant Burning Rate Measurement in a Closed Bomb," Combustion and Flame, Vol. 23, pp 381-397, 1974.

3. Dickey, C. M., "Determination of Burning Characteristics of Propellant," E. J. duPont de Nemours and Company, Explosives Department, Burnside Laboratory, Memorandum Report No. 31, (File BL-135-101), March 1943.

4. Haeuseler, E. and Dehl, W., "State of Development of Testing Procedures for Propellants in the Closed Vessel," Explosivstoffe, Vol. 18, pp 41-52, 1970.

5. Krier, H. and Shimpi, S. A., "Predicting Uniform Gun Interior Ballistics: Part I - An Analysis of Closed Bomb Testing," University of Illinois Technical Report AAE-74-5, July 1974. (Contract DAAA-21-73-C-0549.)

6. Massey, J. M. Jr., "Measurements of Impetus, Covolume and Burning Rate in Solid Propellants," Naval Weapons Laboratory Report No. 1872, Dahlgren, VA, July 1963.

7. Pallingston, Arnold O. and Weinstein, Murray, "Method of Calculation of Interior Ballistic Properties of Propellants from Closed Bomb Data," Picatinny Arsenal Technical Report No. 2005, Dover, NJ, June 1954.

8. Pike, H. H. M. and Hunt, F. R. W., "Chapter V, Combustion at Constant Volume," from F. R. W. Hunt, ed., Internal Ballistics, New York, Philosophical Library, pp 53-66, 1951.

9. Riefler, D. W., and Lowery, D. J., "Linear Burn Rates of Ball Propellants Based on Closed Bomb Firings," Ballistic Research Laboratory Contractor Report No. 172, Aberdeen Proving Ground, MD, August 1974.

10. Robbins, F. W. and Horst, A. W., "Numerical Simulation of Closed Bomb Performance Based on Blake Code Thermodynamic Data," Indian Head Memorandum Report 76-259, Naval Ordnance Station, Indian Head, MD, December 1976.

11. Wallace, William F., "New Formulas for Rapid Calculation of Linear Burning Rates of Solid Propellants," Picatinny Arsenal Technical Report No. 2488, Dover, NJ, April 1958.

12. Wiegand, James H., "A Method of Calculation of the Burning Rate of Powders from dP/dt vs. P Records for Closed Chambers," Ballistic Research Laboratory Report No. 546, Aberdeen Proving Ground, MD, June 1945.

APPENDIX A

Input Requirements for CBRED

Input Requirements for CBRED*

1. Run ID. Provides input file designation for program.

2. Propellant Data.

   a. Type

   b. Weight (grams)

   c. Density (grams/cc)

   d. Grain Type

   e. Length, OD, ID (inches)

   f. Inner Web, Outer Web (inches)

   g. Theoretical Impetus (ft-lb/lb)

   h. Flame Temperature (°K)

   i. Average Molecular Weight of Products (grams/mole)

   j. Covolume (cubic inch per pound)

   k. Gamma (ratio of specific heat)

3. Igniter Data

   a. Type

   b. Weight (grams)

   c. Impetus (ft-lb/lb)

4. Experiment Data

   a. Bomb Volume (cc)

   b. Bomb Temperature (°K)

* The input information listed is actually what is required by the program being documented. Conversion to metric units is being planned.

5. Data Arrays (digital)

   a. Pressure-Time* (Kpsi, milliseconds)

   b. Time Derivative of Pressure-Time* (mega psi, milliseconds)

*The input information listed is actually what is required by the program being documented. Conversion to metric units is being planned.

APPENDIX B

Sample Output, CBRED*

*Program output is currently not in metric units. Conversion is being planned.

RUN ID:	C81V75.027
RUN TITLE:	LOVA STUDY RUN SIX
DATE:	31 JULY 1975
OPERATOR:	AAJ/REB

PROPELLANT DATA:

TYPE:	LOVA F704-35-1 FEM 210-5-029; HMX 65% 2MICRON, 10% 10MICRON		
WEIGHT (GMS):	12.50159		
DENSITY (GM/CC):	1.63000		
INITIAL TEMPERATURE (DEG K):	300.50000		
LOT:	LOT 10A		
SOURCE:	THIOKOL WASATCH UTAH		
GRAIN TYPE:	CY		
LENGTH,OD,ID (IN):	0.02170,	0.25000,	0.00000,
INNER WEB,OUTER WEB (IN):	0.02170,	0.02170,	
THEORETICAL IMPETUS (FT-LB/LB):	319502.00000		
FLAME TEMPERATURE:	2280.84351		
AVERAGE MOLECULAR WEIGHT OF PROD:	19.94000		
CO-VOLUME (CU IN/LB):	31.69000		
GAMMA (RATIO OF SP HTS):	1.27100		
REMARKS:	FLAKE, NON-GRAPHITED, NON-PERFORATED		

IGNITER DATA:

TYPE:	DUPONT 700X
WEIGHT (GMS):	0.50850
IMPETUS (FT-LB/LB):	362530.00000

EQUIPMENT DATA

BOMB VOLUME (CC):	80.90000
BOMB TEMP (DEG K):	300.50000
GAUGE TYPE:	PT-3
CALIBRATION FACTOR (PC/PSI):	1.64320

RESULTS:

THEORETICAL MAX PRESS (KPSIA):	24.50980
OBSERVED MAX PRESS (KPSIA):	22.42971
IGNITER PRESSURE (KPSIA):	0.92221

IGNITION TIME INFORMATION:

TIME TO 10% PMAX (MSEC):	14.06122
TIME TO 90% PMAX (MSEC):	25.42654
TIME TO 100% PMAX (MSEC):	33.55000
TIME FROM 10% TO 90% PMAX (MSEC):	11.36532

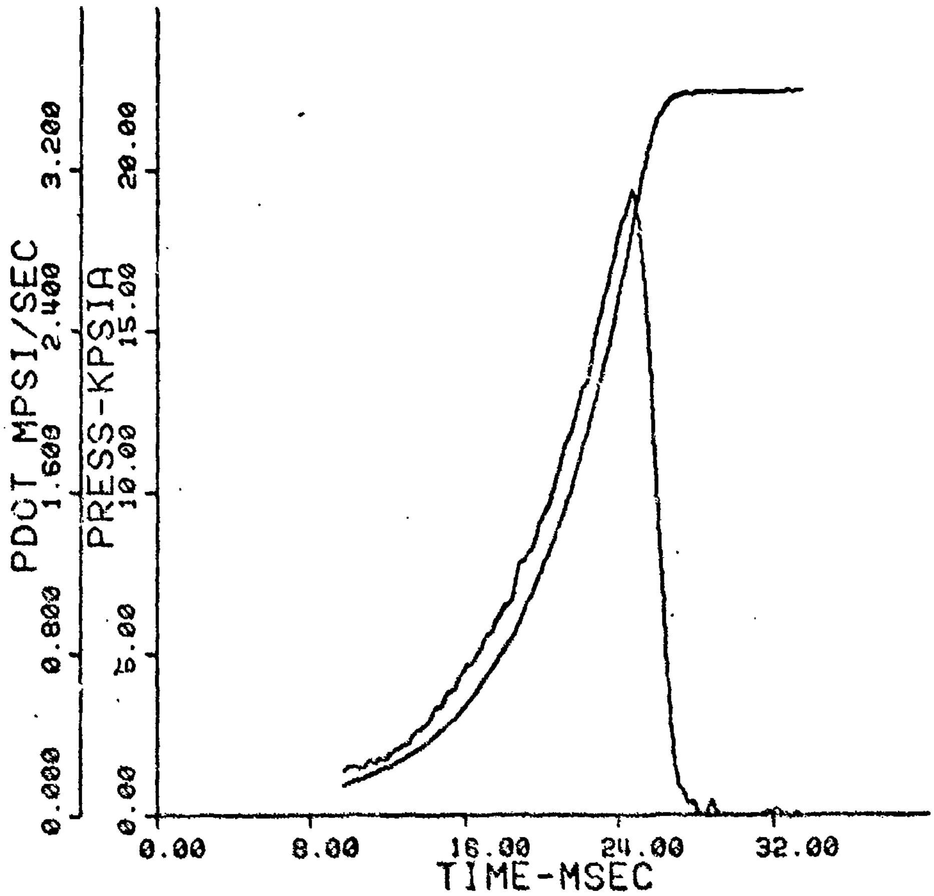
```
QUICKNESS INFORMATION:

PDOT AT .250 PMAX:          1.11212
PDOT AT .375 PMAX:          1.60492
PDOT AT .500 PMAX:          2.09854
PDOT AT .625 PMAX:          2.54956
AVERAGE PDOT:               1.84129

MAXIMUM PDOT (MPSI/SEC):    3.09774     OBSERVED AT P = (KPSIA):    18.20000

HEAT LOSS OPTION:  CONSTANT
HEAT LOSS NUMBER:  1453.51169

INITIAL SURFACE AREA (SQ IN):    50.60207
NUMBER OF GRAINS:                     439
```

CB1V75.027

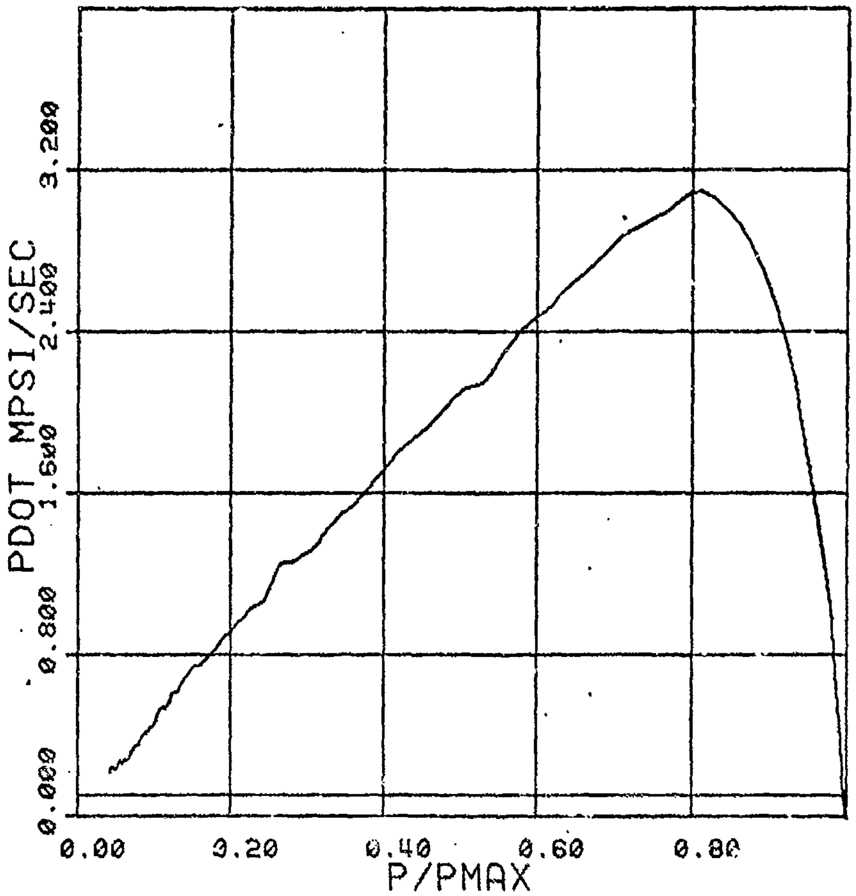
TIME MSEC	PRESS KPSIA	DP/DT MPSI/SEC	RATE IN/SEC	WT FR	SURF FR	WEB BRN INCH	PDOT/PMAX MSEC-1
9.736	0.922	0.216	0.127	0.0000	1.0000	0.0000	0.010
9.986	0.970	0.236	0.136	0.0035	0.9991	0.0001	0.011
10.236	1.030	0.241	0.138	0.0073	0.9981	0.0001	0.011
10.486	1.093	0.233	0.134	0.0109	0.9971	0.0002	0.010
10.736	1.156	0.237	0.137	0.0146	0.9962	0.0003	0.011
10.986	1.215	0.257	0.146	0.0183	0.9952	0.0003	0.011
11.236	1.284	0.262	0.140	0.0224	0.9941	0.0004	0.012
11.486	1.340	0.267	0.150	0.0263	0.9931	0.0005	0.012
11.736	1.417	0.275	0.154	0.0304	0.9920	0.0006	0.012
11.986	1.493	0.278	0.155	0.0346	0.9909	0.0006	0.012
12.236	1.556	0.309	0.168	0.0388	0.9898	0.0007	0.014
12.486	1.637	0.325	0.175	0.0435	0.9885	0.0008	0.014
12.736	1.719	0.342	0.183	0.0482	0.9873	0.0009	0.015
12.986	1.800	0.351	0.187	0.0532	0.9860	0.0010	0.016
13.236	1.895	0.382	0.201	0.0582	0.9846	0.0011	0.017
13.486	1.990	0.413	0.214	0.0638	0.9831	0.0012	0.018
13.736	2.101	0.425	0.219	0.0695	0.9816	0.0013	0.019
13.986	2.211	0.443	0.227	0.0755	0.9800	0.0014	0.020
14.236	2.322	0.472	0.240	0.0816	0.9784	0.0015	0.021
14.486	2.447	0.531	0.266	0.0883	0.9766	0.0017	0.024
14.736	2.584	0.531	0.266	0.0934	0.9747	0.0018	0.024
14.986	2.717	0.579	0.280	0.1026	0.9728	0.0019	0.026
15.236	2.870	0.612	0.303	0.1104	0.9707	0.0021	0.027
15.486	3.023	0.636	0.313	0.1184	0.9686	0.0022	0.028
15.736	3.191	0.685	0.335	0.1269	0.9663	0.0024	0.031
15.986	3.365	0.726	0.353	0.1359	0.9639	0.0026	0.032
16.236	3.551	0.746	0.363	0.1453	0.9613	0.0027	0.033
16.486	3.738	0.769	0.373	0.1548	0.9588	0.0029	0.034
16.736	3.937	0.812	0.392	0.1647	0.9561	0.0031	0.036
16.986	4.143	0.846	0.408	0.1750	0.9533	0.0033	0.038
17.236	4.363	0.890	0.431	0.1858	0.9504	0.0035	0.040
17.486	4.589	0.923	0.446	0.1970	0.9473	0.0037	0.041
17.736	4.830	0.974	0.466	0.2087	0.9442	0.0040	0.043
17.986	5.077	1.024	0.489	0.2209	0.9409	0.0042	0.046
18.236	5.339	1.049	0.501	0.2335	0.9374	0.0045	0.047
18.486	5.605	1.111	0.530	0.2464	0.9339	0.0047	0.050
18.736	5.899	1.237	0.586	0.2605	0.9300	0.0050	0.055
18.986	6.213	1.254	0.595	0.2754	0.9259	0.0053	0.056
19.236	6.529	1.289	0.612	0.2904	0.9218	0.0056	0.057
19.486	6.855	1.322	0.628	0.3055	0.9175	0.0059	0.059
19.736	7.193	1.395	0.663	0.3218	0.9131	0.0062	0.062
19.986	7.551	1.467	0.696	0.3385	0.9084	0.0066	0.065
20.236	7.925	1.520	0.722	0.3559	0.9036	0.0069	0.068
20.486	8.311	1.584	0.753	0.3738	0.8986	0.0073	0.071
20.736	8.717	1.663	0.791	0.3925	0.8933	0.0077	0.074
20.986	9.142	1.750	0.833	0.4121	0.8878	0.0081	0.078
21.236	9.592	1.833	0.874	0.4325	0.8820	0.0085	0.082
21.486	10.059	1.899	0.907	0.4537	0.8760	0.0089	0.085

CB1V75.027

TIME MSEC	PRESS KPSIA	DP/DT MPSI/SEC	RATE IN/SEC	WT FR	SURF FR	WEB BRN INCH	PDOT/PMAX MSEC-1
21.736	10.542	1.975	0.945	0.4755	0.8698	0.0094	0.088
21.986	11.048	2.069	0.992	0.4982	0.8632	0.0099	0.092
22.236	11.577	2.127	1.023	0.5217	0.8565	0.0104	0.095
22.486	12.118	2.198	1.056	0.5456	0.8496	0.0109	0.098
22.736	12.677	2.344	1.133	0.5706	0.8423	0.0115	0.104
22.986	13.270	2.450	1.189	0.5970	0.8346	0.0120	0.109
23.236	13.900	2.538	1.232	0.6241	0.8266	0.0127	0.113
23.486	14.547	2.645	1.293	0.6522	0.8183	0.0133	0.118
23.736	15.221	2.746	1.349	0.6813	0.8096	0.0139	0.122
23.986	[illegible]	2.859	1.416	0.7114	0.8006	0.0145	[illegible]
24.236	15.653	2.947	1.463	0.7424	0.7912	0.0154	0.131
24.486	17.396	3.022	1.509	0.7739	0.7816	0.0161	0.135
24.736	18.166	3.098	1.557	0.8062	0.7717	0.0169	0.138
24.986	18.934	3.002	1.521	0.8383	0.7618	0.0176	0.134
25.236	19.667	2.828	1.446	0.8687	0.7523	0.0184	0.126
25.486	20.340	2.535	1.310	0.9057	0.7426	0.0191	0.113
25.736	20.920	2.132	1.115	0.9211	0.7359	0.0197	0.095
25.986	21.402	1.668	0.887	0.9409	0.7296	0.0202	0.074
26.236	21.769	1.268	0.683	0.9563	0.7246	0.0206	0.056
26.486	22.020	0.822	0.463	0.9676	0.7218	0.0209	0.037
26.736	22.184	0.474	0.286	0.9747	0.7187	0.0210	0.021
26.986	22.272	0.244	0.169	0.9791	0.7173	0.0212	0.011
27.236	22.313	0.140	0.116	0.9817	0.7165	0.0212	0.006
27.486	22.345	0.093	0.092	0.9838	0.7158	0.0213	0.004
27.736	22.360	0.058	0.074	0.9853	0.7153	0.0213	0.003
27.986	22.370	0.056	0.073	0.9868	0.7149	0.0214	0.002
28.236	22.381	-0.003	0.043	0.9879	0.7145	0.0214	-0.000
28.486	22.381	-0.003	0.043	0.9887	0.7142	0.0214	-0.000
28.736	22.384	0.049	0.078	0.9897	0.7139	0.0214	0.002
28.986	22.403	0.058	0.078	0.9912	0.7134	0.0215	0.002
29.236	22.405	-0.003	0.043	0.9922	0.7131	0.0215	-0.000
29.486	22.405	0.000	0.045	0.9931	0.7128	0.0215	0.000
29.736	[illegible]	0.000	0.045	[illegible]	0.7125	0.0215	0.000
29.986	22.425	0.000	0.045	0.9940	0.7123	0.0216	0.000
30.236	22.405	0.000	0.045	0.9956	0.7120	0.0216	0.000
30.486	22.405	0.000	0.045	0.9965	0.7117	0.0216	0.000
30.736	22.405	0.000	0.045	0.9974	0.7114	0.0216	0.000
30.986	22.405	0.000	0.045	0.9982	0.7112	0.0217	0.000
31.236	22.405	0.000	0.045	0.9991	0.7109	0.0217	0.000
31.486	22.404	0.005	0.047	0.9999	0.7106	0.0217	0.000
31.736	22.410	0.024	0.047	1.0010	0.0020	0.0217	0.001
31.986	22.413	0.014	0.047	1.0020	0.0000	0.0217	0.001
32.236	22.421	0.034	0.047	1.0031	0.0000	0.0218	0.002
32.486	22.425	0.007	0.047	1.0042	0.0000	0.0218	0.000
32.736	22.428	0.004	0.047	1.0051	0.0000	0.0218	0.000
32.986	22.425	-0.006	0.047	1.0059	0.0000	0.0219	-0.000
33.236	22.427	0.013	0.047	1.0068	0.0000	0.0219	0.001



RUN ID: CBIV76.027
RUN TITLE: LOVA STUDY RUN SIX
PROP TYPE: LOVA F76N-56-1 FEM 210-6-020; HMX 65% 2MICRON, 10% 10MICRON
GRAIN TYPE: OY



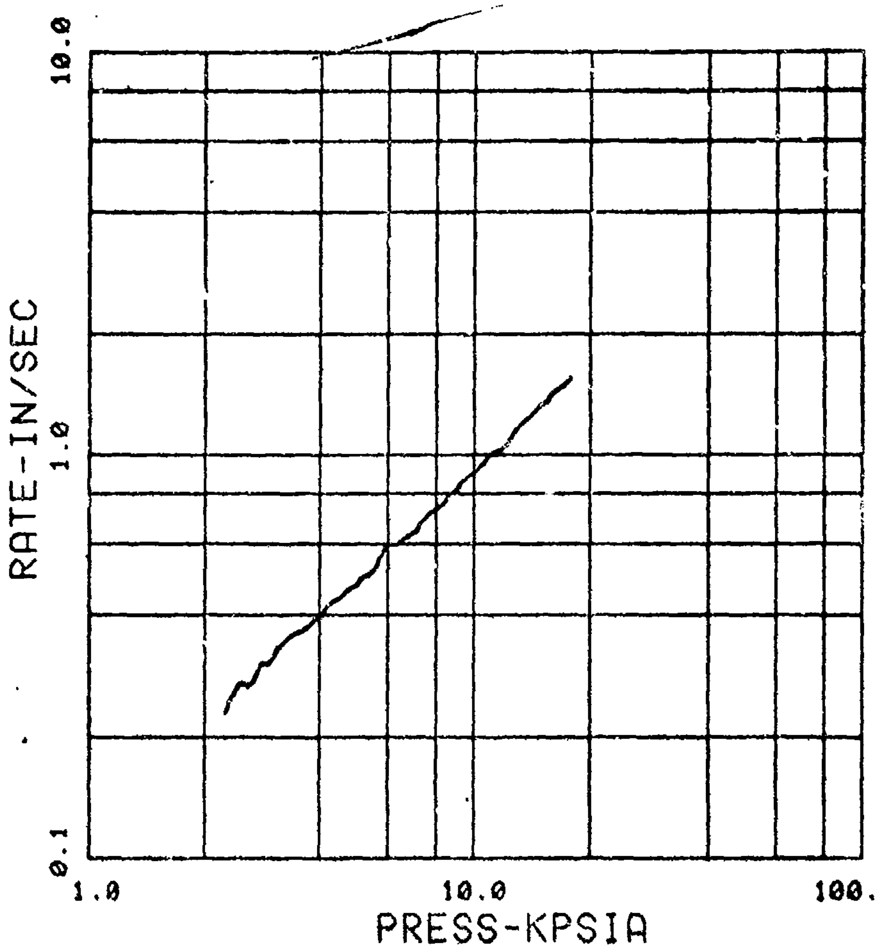
RUN ID: CB1V76.027

RUN TITLE: LOVA STUDY RUN SIX

PROP TYPE: LOVA F704-35-1 PEM 218-5-029; HMX 65% 2MICRON, 10% 10MICRON

GRAIN TYPE: 0Y

PDOT	AT	P/PMAX
1.112		5.607
1.806		8.411
2.099		11.215
2.550		14.019



RUN ID: C81V75.027

RUN TITLE: LOVA STUDY RUN SIX

PROP TYPE: LOVA F704-3G-1 FEM 218-5-020; HMX 85% 2MICRON, 10% 10MICRON

GRAIN TYPE: CY

THE CONSTANTS IN THE EQUATION R = A*P**N ARE

A: 0.000233

N: 0.890

FOR P/PMAX 0.100 TO 0.800

COEFFICIENT OF DETERMINATION : 0.9989

PER CENT ROOT MEAN ERROR : 1.6034

APPENDIX C

Form Function Equations
used in CBRED

Equation for FORM SP

Form Function of a Sphere. S, Surface Area, as a function of x, The Distance Burned

$W = D$

where: D = initial diameter of sphere

W = propellant web

x = depth burned at time t.

$S = 0$ for $W \leq 2x$

Otherwise:

$D' = D-2x$

Surface Area

$$A=4\pi\left(\frac{D'}{2}\right)^2$$

Equations for FORM CY

Form Function of a Right Circular Cylinder. S, Surface Area as a Function of x, the Distance Burned

$W = D$

where: D = initial grain diameter.

W = propellant web

x = depth burned at time t

$S = 0$ for $L \leq 2x$
(L = initial grain length)

$S = 0$ for $W \leq 2x$

Otherwise:

$D' = D - 2x$
$L' = L - 2x$

<u>End Area</u>:

$$E = \pi/4 \, (D')^2$$

<u>Surface Area</u>:

$$S = 2E + \pi L' D'$$

Equations for FORM1

Form Function of a Single Perforated Right Circular Cylinder (Axially Symmetrical). S, Surface Area, as a function of x, the Distance Burned.

$$W = \frac{D-D_p}{2}$$

where:

W = propellant web

D = initial grain diameter
D_p = initial perforation diameter

x = depth burned at time t.

$S = 0$ for $L \leq 2x$
(L= initial grain length)
$S = 0$ for $W \leq 2x$

Otherwise:

$$D' = D-2x$$
$$L' = L-2x$$
$$D_{p'} = D_p + 2x$$

<u>End Area</u>:

$$E = \frac{\pi}{4} [(D')^2 - (D_{p'})^2]$$

<u>Surface Area</u>:

$$S=2E + \pi L' (D' + D_{p'})$$

Equations for FORM 7

Form Function of a Seven Perforated Right Circular Cylinder (Axially Symmetrical). S, Surface Area, as a Function of x, the distance burned.

I. To splintering:

$$W = \frac{D - 3\,D_p}{4}$$

where:

W = propellant web
D = initial grain diameter
D_p = initial perforation diameter

x = depth burned at time t

$S = 0$ for $L' \leq 2x$
(L' = instantaneous grain length)

$S = S_{max}$ for $W=2x$

$S = < S_{max}$ for $W<2x$

for $0 \leq x$, define

$D' = D-2x$
$L' = L-2x$
(L = initial grain length)
$D_{p'} = D_p+2x$

Then, for $0 \leq 2x \leq W$

End Area

$$E = \frac{\pi}{4} \left[(D')^2 - 7\,(D_{p'})^2 \right]$$

Surface Area:

$$S = 2E + \pi\, L' \,(D' + 7\, D_{p'})$$

Form Function of a Seven Perforated Right Circular Cylinder (Axially Symmetrical). Surface Area, S, as a Function of x, The Distance Burned (continued).

II. After Splintering*

define: $W_w = D_p + W$ and let

$$C = \min\left\{L, \frac{D^2 - D_p^2 + 4W_w^2 - 2W_w D\sqrt{3}}{2(D + D_p - W_w\sqrt{3})}\right\}$$

Then for $W < 2x \leq C$, let

$$\Theta = 2\cos^{-1}\left\{\min\left(\frac{W_w}{D_{p'}}, 1\right)\right\}$$

$$\alpha = \cos^{-1}\left\{\min\left(\frac{1/4\left[(D')^2 - (D_{p'})^2\right] + W_w^2}{W_w D'}, 1\right)\right\}$$

$$\beta = \cos^{-1}\left\{\max\left(\frac{1/4\left[(D_{p'})^2 - (D')^2\right] + W_w^2}{W_w D_{p'}}, -1\right)\right\} - \frac{\Theta}{2} - \frac{\pi}{3}$$

E_1 = End area of outer slivers

for $\alpha < \pi/6$

$$E_1 = 3\,D'\,W_w \sin\alpha + 3/2\left[(D')^2(\pi/6 - \alpha) - W_w^2\sqrt{3} - (D_{p'})^2(\beta + 1/2\sin\Theta)\right]$$

$E_1 = 0$ for $\alpha \geq \pi/6$

S_1 = Surface area of outer slivers

for $\alpha < \pi/6$

$$S_1 = 2E_1 + (6\beta Dp' + (\pi - 6\alpha)\,D')\,L'$$

$S_1 = 0$ for $\alpha \geq \pi/6$

* Treatment developed by Mr. Franz Lynn, USABRL.

E_2 = End area of inner slivers
for $\Theta < \pi/3$

$$E_2 = 3/2\left[w_w^{\ 2}\ \sqrt{3} - 3/2(D_{p'})^2\ (\sin\Theta + \pi/3 - \Theta)\right]$$

$E_2 = 0$ for $\Theta \geq \pi/3$

S_2 = Surface area of inner slivers
for $\Theta < \pi/3$

$$S_2 = 2E_2 + 9D_{p'}\ (\pi/3 - \Theta)L'$$

$S_2 = 0$ for $\pi/3 \leq \Theta$

S = Total surface area of slivers

$S = S_1 + S_2$

E = Total end area
$E = E_1 + E_2$

for $C < 2x$, $E=0$, $S=0$

Equations for FORM 19

Form Function for a Nineteen Perforated Right Circular Cylinder (Axially Symmetrical). S, Surface Area, as a Function of x, The Distance Burned.

I. To Splintering

$$W = \frac{D - 5\,D_p}{6}$$

where:

W = propellant web
D = initial grain diameter
D_p = initial perforation diameter

x = depth burned at time t
$S = 0$ for $L' \leq 2x$
(L' = instantaneous grain length)
$S = S_{max}$ for $W = 2x$
$S < S_{max}$ for $W < 2x$

for $0 \leq x$, define:

$D' = D - 2x$
$L' = L - 2x$
(L=initial grain length)
$D_{p*} = D_p + 2x$

Then, for $0 \leq 2x \leq W$

End Area

$$E = \frac{\pi}{4}\left[(D')^2 - 19\,(D_{p'})^2\right]$$

Surface Area

$$S = 2E + \pi L'\,(D' + 19\,D_{p'})$$

F(Function of a Nineteen Perforated Right Circular Cylinder (Axially Symm. trical). Surface Area S, as a function of x, The Distance Burned. (continued).

II. After Slivering*

define: $W_w = D_p + W$ and let

$$C = \min \left\{ L,\ 1/2 \left[D-D_p-W_w \sqrt{\frac{12[(D+D_p)^2 - 16W_w^2]}{[D+D_p]^2 - 12W_w^2}} \right] \right\}$$

Then, for $w<2x\leq C$, let

$$\Theta = 2\cos^{-1}\left\{ \min\left(\frac{W_w}{D_{p'}},\ 1 \right) \right\}$$

$$\alpha_1 = \cos^{-1}\left\{ \min\left(\frac{1/8\ [(D')^2 - (D_{p'})^2] + 2\,W_w^2}{W_w D'},\ 1 \right) \right\}$$

$$\alpha_2 = \cos^{-1}\left\{ \min\left(\frac{1/4\ [(D')^2] - (D_{p'})^2 - (D_{p'})^2] + 3\,W_w^2}{W_w D' \sqrt{3}},\ 1 \right) \right\}$$

$$\beta_1 = \cos^{-1}\left\{ \max\left(\frac{1/8\ [(D_{p'})^2 - (D')^2] + 2\,W_w^2}{W_w D_{p'}},\ -1 \right) \right\}$$

$$\beta_2 = \cos^{-1}\left\{ \max\left(\frac{1/4\ [(D_{p'})^2 - (D')^2] + 3\,W_w^2}{W_w D_{p'} \sqrt{3}},\ -1 \right) \right\}$$

and:

$\alpha = \alpha_1 + \alpha_2$

$\beta = \beta_1 + \beta_2 - \Theta - 5\pi/6$

* Treatment developed by Mr. Franz Lynn, USABRL.

E_1 = End area of Outer Slivers
for $\alpha < \pi/6$

$$E_1 = 3\,D'\,W_w(2\sin\alpha_1 + \sqrt{3}\sin\alpha_2) - 6\,W_w^{\,2}\sqrt{3}$$

$$+ 3/2\,[(D')^2\,(\pi/6-\alpha) - (D_{p'})^2\,(\sin\theta + \beta)]$$

$E_1 = 0$ for $\alpha \geq \pi/6$

S_1 = Surface Area of Outer Slivers
for $\alpha < \pi/6$

$$S_1 = 2E_1 + 6\,[\,D'\,(\pi/6-\alpha) + D_{p'}\,\beta] \cdot L'$$

$S_1 = 0$ for $\alpha \geq \pi/6$

E_2 = End area of Inner Slivers
for $\theta < \pi/3$

$$E_2 = 6\,[W_w^{\,2}\sqrt{3} - 3/2\,(D_{p'})^2\,(\sin\theta + \pi/3 - \theta)]$$

$E_2 = 0$ for $\theta \geq \pi/3$

S_2 = Surface Area of Inner Slivers
for $\theta < \pi/3$

$$S_2 = 2E_2 + 36\,D_{p'}(\pi/3 - \theta)L'$$

$S_2 = 0$ for $\theta \geq \pi/3$

S = Total Surface Area of Slivers
$S = S_1 + S_2$

E = Total End Area
$E = E_1 + E_2$

for $C<2x$, $E = 0$ and $S = 0$

APPENDIX D

Derivation of Mass Burning Rate Equation for CBRED

Derivation of the Mass Burning Rate Equation for CBRED

The same order of presentation is followed as in the text. The Equation of State is presented first, the Energy Equation, second, followed by the Mass Burning Rate Equation.

(1) Equation of State of Gas

$$PV_s = w_s R_s T_s \tag{23}$$

where:

P = pressure

V_s = system volume

$$= V_b - \frac{(c_a + c_p)}{\rho} + \frac{(w_a + w_p)}{\rho} - w_s \eta$$

V_b = empty bomb volume

c_a = starting weight of ignition aid

c_p = starting weight of propellant

ρ = solid propellant density (assumed same for ignition aid)

w_a = weight of ignition aid burned*

w_p = weight of propellant burned*

w_s = $w_r + w_i + w_{al} + w_{pl}$

w_r = weight of air in chamber

w_i = weight of initiator combustion products in chamber

w_{al} = weight of ignition aid combustion products in chamber*

w_{pl} = weight of propellant combustion products in chamber*

η = covolume

$$R_s = \frac{R_u m_T}{w_s}$$

R_u = universal gas constant

$$m_T = \frac{w_r}{M_r} + \frac{w_i}{M_i} + \frac{w_{al}}{M_a} + \frac{w_{pl}}{M_p}$$

M_r = molecular weight of air (taken as 29.)
M_i = molecular weight of initiator combustion products
M_a = molecular weight of ignition aid combustion products
M_p = molecular weight of propellant combustion products

* Note: For a closed bomb system there is an obvious redundancy between W_p and W_{p1} and W_a and W_{a1}. But for a leaking, or vented vessel, the distinctions are important.

(2) Energy Balance Equation

It is more convenient to describe the energy balance dynamically. The following governing equation applies:

$$\frac{d(C_V w_s T_s)}{dt} = C_V\ [T_{0a}\ \dot{w}_a + T_{0p}\ \dot{w}_p] - \dot{H}_L - C_P\ T_s\ \dot{w}_n \qquad (24)$$

where:

C_V = heat capacity at constant volume (assumed same for ignition aid)

T_{0a} = isochoric adiabatic flame temperature of the ignition aid

T_{0p} = isochoric adiabatic flame temperature of the propellant

$\dot{w}_a = AP^n$ By definition. Ignition aid mass burning rate.

$\dot{w}_p$ = mass burning rate of the propellant.

$\dot{H}_L$ = heat loss rate

C_p = heat capacity at constant pressure

$$\dot{W}_n = g \frac{P_{st} A_t}{C^*}$$

where:

g = gravitational constant

P_{st} = stagnation pressure

A_t = effective throat area (sonic control assumed)

C^* = characteristic discharge velocity

$$= \left[\frac{g \, R_u \, T_{st}}{\tau^2 \quad M_s}\right]^{1/2}$$

T_{st} = stagnation temperature

M_s = system molecular weight

τ^2 = a function of the specific heat ratio

$$\tau^2 = \gamma \left(\frac{2}{\gamma + 1}\right)^{\left(\frac{\gamma + 1}{\gamma - 1}\right)}$$

(3) Rate of Conversion of Solid to Gas

Solving the Equation of State (23) for T_s and differentiating yields:

$$\frac{dT_s}{dt} = \frac{1}{R_s w_s}\left[P\dot{V}_s + V_s\dot{P} - \frac{PV_s}{R_s w_s}\left(w_s\dot{R}_s + R_s\dot{w}_s\right)\right] \tag{25}$$

where:

$$\dot{V}_s = -w_s\,\dot{\eta} - \eta\dot{w}_s\,\frac{(\dot{w}_a + \dot{w}_p)}{\rho}$$

$$\dot{\eta} = \frac{d\eta}{dP} \times \frac{dP}{dt} \quad \text{By definition}$$

$$\dot{R}_s = \frac{R_u}{w_s}\left[\dot{m}_T - \frac{m_T\,\dot{w}_s}{W_s}\right]$$

$$\dot{m}_T = \frac{\dot{w}_r}{M_r} + \frac{\dot{w}_i}{M_i} + \frac{\dot{w}_{a1}}{M_a} + \frac{\dot{w}_p}{M_p} - \frac{w_{p1}\dot{w}_n}{M_p w_s} - \frac{W_{p1}\dot{M}_p}{(M_p)^2}$$

$$\dot{w}_r = -\frac{w_r}{W_s} \times \dot{w}_n \quad \text{By definition}$$

$$\dot{w}_i = -\frac{w_i}{w_s} \times \dot{w}_n \quad \text{By definition}$$

$$\dot{w}_{a1} = \dot{w}_a - \frac{w_{ai}}{w_s}\,\dot{w}_n \quad \text{By definition}$$

$$\dot{w}_s = \dot{w}_r + \dot{w}_i + \dot{w}_{al} + \dot{w}_p - \frac{w_{pl}}{w_s} \dot{w}_n$$

Note also:

$$\dot{w}_{pl} = \dot{w}_p - \frac{w_{pl}}{w_s} \dot{w}_n \quad \text{By definition}$$

Differentiating the left hand side of Equation (24) as indicated gives:

$$C_V w_s \dot{T}_s + C_V T_s \dot{w}_s + w_s T_s \dot{C}_V = C_V\left(T_{0a} \dot{w}_a + T_{0p} \dot{w}_p\right) - \dot{H}_L - C_p T_s \dot{w}_n \qquad (26)$$

where:

$$\dot{C}_V = \frac{d (C_V)}{dP} \times \frac{dP}{dt} \qquad \text{by definition}$$

Solving Equation (26) for the rate of change of system temperature with time ($\dot{T}_s$) one may simultaneously solve with Equation (25), which on expansion of terms and appropriate manipulation yields the following equation for mass burning rate:

$$\frac{dw_p}{dt} = \left\{ \frac{V_s \dot{P}}{R_s} - \frac{P w_s \dot{\eta}}{R_s} + \frac{\dot{H}_L}{C_V} + \gamma T_s \dot{w}_n + \frac{w_s T_s \dot{C}_V}{C_V} + \frac{P \dot{w}_a}{\rho\, R_s} T_{0a} \dot{w}_a \right.$$

$$\left. - \left[\frac{P\eta}{R_s} - \frac{PV_s\, m_T R_u}{(R_s w_s)^2} \right] \left[\dot{w}_r + \dot{w}_i + \dot{w}_{a1} - \frac{w_{p1}\, \dot{w}_n}{w_s} \right] - \frac{PV_s w_s R_u}{(R_s w_s)^2} \left[\frac{\dot{w}_r}{M_r} + \frac{\dot{w}_i}{M_i} + \frac{\dot{w}_{a1}}{M_a} - \frac{w_{p1}\, \dot{w}_n}{M_p w_s} - \frac{w_{p1}\, \dot{M}_p}{(M_p)^2} \right] \right\}$$

$$\Bigg/ \left[\frac{P\eta}{R_s} - \frac{PV_s\, m_T\, R_u}{(R_s w_s)^2} - \frac{P}{\rho\, R_s} + \frac{PV_s w_s R_u}{(R_s w_s)^2\, M_p} + T_{OP} \right] \qquad (27)$$

APPENDIX E

Equations for Wall Temperature Computations in WALTEM

Heat loss is computed by coupling transient conduction in the bomb wall with the convective and radiative transfer to the wall. In the wall, the governing equation is

$$\frac{\delta T_w}{\delta t} = \frac{\delta^2 T_w}{\delta X^2} \cdot \alpha \qquad (23)$$

where T_w = temperature field within the wall

α = thermal diffusivity

X = radial distance into the wall

The initial condition is a uniform temperature (set at 298K). The boundary conditions are:

at $X = 0$: $-K \frac{\delta T}{\delta X} = H_L/A_w$

at $X \to \infty$ $\frac{\delta T}{\delta X} = 0$

An explicit centered difference scheme is used for the calculation. At the boundaries the scheme is as follows:

at $X = 0$:

$$T_o^{n+1} = T_o^{\,n} + \frac{\alpha \Delta t}{(\Delta X)^2} \left[\frac{H_L}{A_w K} \; 2(\Delta X) \; - 2T_1 + 2T_2 \right]^n$$

where $n + 1$ is the new time level

n the old time level

T_1 the first interior point

T_2 the second interior point

at back boundary $X = N \, \Delta X$:

$T_N = T_{N-1}$

N = number of grid points

APPENDIX F

Capsule Summary of Suboutines

Capsule Summary of Subroutines

ACQUIRE	Subroutine to get file data, allow update and start process
HTLOSS	Subroutine to calculate average heat loss value, average heat transfer coefficient
HTFIT	Subroutine to fit the decay portion of the P-t curve to find heat loss coefficients.
SUMUP	Subroutine to print summary sheet of analysis.
REDUCE	Driver for the differential equation solver.
EVES	Subroutine solves N simultaneous first order differential equations by the Adams method.
SETUP	Subroutine sets the initial conditions for the integration and defines the accuracy required in the solution.
DIFEQ	This subroutine evaluates the derivative values at each proposed step in the solution. On each call T1 contains the current time, and Y's are the current integrated values. The results of a call may be rejected and the step size cut in order to maintain accuracy.
PRINT	This subroutine is called to output accepted values during the integration procedure.
FINDTP	A subroutine for table lookup with linear interpolation. A direct access read lookup modification of FIND1.
FIND1	A subroutine for table lookup with linear interpolation. Extrapolates values out of table range, remembers last argument value and begins search from that value.
SIMEQ	A subroutine solving L equations in N unknowns, with N sets of right hand constants.
RCALC	Subroutine to do least squares fit on burn rate data.
VPLOT	Versatech* unit plotting package.

*Registered trademark, does not constitute endorsement by the US Army.

APPENDIX G

Program Listing. CBRED

```
      C     MAIN DRIVER FOR LATEST REDUCTION PROGRAM. 10/14/75
0001        COMMON RUNID(5),RTITLE(18),DATE(3),OPERN(5),PROPN(18),
           1 PSORCE(18),PRLOT(18),PREM(18),TIGNR(18),GAGE(18),
           2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
           3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
           4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
           5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
           6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
           7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
           8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
           9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW,RATE,RL
0002        COMMON /GENE/ WIDP(5),WODP(5),UCR(5),SFAC(5,5),TDEL(5),
           1 WDEV,TDEV,TUST
0003        COMMON /BLAH/ PLO, PHI, ACO, XNC, RSQ, RMS
0004        COMMON /KEVIN/ TE(35), XT(35)
0005        DATA DUMM/'WOW '/
0006        WRITE (11,197) WOW
0007   197  FORMAT (A4)
0008        REWIND 11
0009        CALL ACQUIRE
0010        CALL HTLOSS
0011        SPACE2(3) = 0.0
0012        IF (IHL.EQ.2) GO TO 1976
0014        CALL HTFIT
0015   1976 CONTINUE
0016        CALL SUMUP
0017        CALL REDUCE
0018        CALL RCALC
0019        TYPE 100
0020   100  FORMAT (///)
0021        CALL VPLOT
0022        STOP
0023        END
```

```
      SUBROUTINE ACQUIRE
C     SUBROUTINE TO GET FILE DATA, ALLOW UPDATE AND START PROCESS
      COMMON RUNID(5),RTITLE(10),DATE(3),OPERN(5),PROPN(10),
     1 PSORCE(10),PRLOT(10),PREM(10),TIGNR(10),GAGE(10),
     2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
     3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
     4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
     5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
     6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
     7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
     8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
     9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW
      COMMON /GENE/ WIDP(5),WODP(5),UCR(5),SFAC(5,5),TDEL(5),
     1 WDEV,TDEV,TUST
      COMMON /BLAH/ PLO, PHI, ACO, XNC
      DIMENSION A9(4)
      DATA AY/'Y'/,A9/0.25,.375,.50,.625/,BL/'    '/,
     1 AVG/'AVE '/,P1/'1P  '/,P7/'7P  '/,P19/'19P '/,
     2 SP/'SPH '/,CY/'CY  '/
      DIMENSION LIST (400)
      EQUIVALENCE (LIST(1),RUNID(1))
      EQUIVALENCE (IBUG,LIST(398))
      EQUIVALENCE (ISK1,LIST(399)),(KTOT,LIST(400))
      EQUIVALENCE (ATH,SPACE1(10)),(PBLOW,SPACE1(11)),
     1 (FAID,SPACE1(12)),(TAID,SPACE1(13)),(CAID,SPACE1(15)),
     2 (XMA,SPACE1(14))
      CALL ASSIGN (2,'SY:CBDAT.001',0,'SCR')
      DEFINE FILE 2 (3000,6,U,MZ)
      TYPE 300
  300 FORMAT (5X,'ENTER SMOOTHED TAPE ID'/)
      CALL ASSIGN (3,'FILNAM.EXT',-1,'RDO')
      DEFINE FILE 3(3100,4,U,MY)
      WDEV = 0.0
      TDEV = 0.0
      DO 69 I = 1,100
      J = 4*I
      L = J - 3
   69 READ (3'I) (LIST(K), K = L,J)
      K = 0
      IBUG = 0
      DPMAX = 0.0
      RHOC = SPACE2(1)
      PMAX = 0.0
      FAID = 362000.
      TAID = 3000.
      RU = 1544.*1.0
      XMA = RU*TAID/FAID
      CAID = 0.0
      ATH = 0.0
      PBLOW = 0.0
      KM = KTOT + 100
        DO 68 J = 101,KM
```

```
      READ (3'J) B1, C1
      I = J - 100
      I1 = (I-1)*ISK1 + 1
      T1 = I1*STIME*1.0E-03
      K = K + 1
```

```
0043         IF (B1.LT.PMAX) GO TO 88
0045         PMAX = B1
0046         TMAX = TI
0047         NPMA = K
0048    88   IF (C1.LT.DPMAX) GO TO 68
0050         PPM = B1
0051         DPMAX = C1
0052    68   WRITE (2'I) TI, B1, C1
0053         MEM7 = 1
0054         PDES = 0.99*PMAX
0055         CALL FINDTP (PDES,TMAX,3,2,1,2,NPMA,MEM7,MZ)
0056         PDES = 0.1*PMAX
0057         CALL FINDTP (PDES,T10,3,2,1,2,NPMA,MEM7,MZ)
0058         PDES = 0.9*PMAX
0059         CALL FINDTP (PDES,T90,3,2,1,2,NPMA,MEM7,MZ)
0060         T1090 = T90 - T10
0061         SUM = 0.0
0062         DO 62 I = 1,4
0063         P9(I) = A9(I)*PMAX
0064         CALL FINDTP (P9(I),DP9(I),3,2,3,2,NPMA,MEM7,MZ)
0065    62   SUM = SUM + DP9(I)
0066         DP9(5) = SUM/4.0
0067         P9(5) = AVG
0068         ENDFILE 3
0069         FRAC = 1.0
0070         IHL = 2
0071         H = 0.0
0072         XMI = 68.62
0073         IF (PCORR.GT.150000.) XMI = 25.
0075         TYPE 301
0076   301   FORMAT (5X,'IS THIS TO BE A'/
            1 5X,'STANDARD ANALYSIS, Y OR N?')
0077         ACCEPT 302, ANSP
0078   302   FORMAT (A1)
0079         CALL PLOT (27,12,4)
0080         SPACE2(2) = 10.1
0081         PLO = 0.1
0082         PHI = 0.0
0083         IF (ANSP.EQ.AY) GO TO 99
0085         TYPE 303, RHOC
0086   303   FORMAT (5X,'DENSITY',F12.5)
0087         ACCEPT 304, TEMP
0088   304   FORMAT (6E12.0)
0089         IF (TEMP.NE.0.0) RHOC = TEMP
0091         TYPE 305, PCORR
0092   305   FORMAT (5X,'IGNITER IMPETUS',F12.5)
0093         ACCEPT 304, TEMP
0094         IF (TEMP.NE.0.0) PCORR = TEMP
0096         TYPE 306, WGHTI
0097   306   FORMAT (5X,'IGNITER WEIGHT',F12.5)
0098         ACCEPT 304, TEMP
0099         IF (TEMP.NE.0.0) WGHTI = TEMP
```

```
      IF (PCORR.GT.150000.) XMI = 25.
      TYPE 396, XMI
396   FORMAT (5X,'IGNITER MOL WEIGHT',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) XMI = TEMP
```

```
0108          TYPE 1305, FAID
0109     1305 FORMAT (5X,'IGNITER AID IMPETUS',F12.5)
0110          ACCEPT 304, TEMP
0111          IF (TEMP.NE.0.0) FAID = TEMP
0113          TYPE 1306, CAID
0114     1306 FORMAT (5X,'IGNITER AID WEIGHT',F12.5)
0115          ACCEPT 304, TEMP
0116          IF (TEMP.NE.0.0) CAID = TEMP
0118          CAID = CAID/454.
0119          TYPE 1396, TAID
0120     1396 FORMAT (5X,'IGNITER AID TEMPERATURE',F12.5)
0121          ACCEPT 304, TEMP
0122          IF (TEMP.NE.0.0) TAID = TEMP
0124          XMA = RU*TAID/FAID
0125          CALL PLOT (27,12,4)
0126          TYPE 307, FFID
0127     307  FORMAT (5X,'GRAIN TYPE',2X,A4)
0128          ACCEPT 308, TEMP
0129     308  FORMAT (A4)
0130          IF (TEMP.NE.BL) FFID = TEMP
0132          TYPE 309, H
0133     309  FORMAT (5X,'HEAT LOSS NUMBER',F12.5)
0134          ACCEPT 304, TEMP
0135          IF (TEMP.NE.0.0) H = TEMP
0137          TYPE 310, IHL
0138     310  FORMAT (5X,'HEAT LOSS OPTION',I4)
0139          ACCEPT 311, IT
0140     311  FORMAT (I1)
0141          IF (IT.NE.0) IHL = IT
0143          TYPE 991, SPACE2(2)
0144     991  FORMAT (5X,'BOMB WALL AREA', F12.5)
0145          ACCEPT 304, TEMP
0146          IF (TEMP.NE.0.0) SPACE2(2) = TEMP
0148          TYPE 312
0149     312  FORMAT (5X,'AVERAGE THERMOCHEMISTRY'/
             1 5X,'IS TO BE USED, Y OR N?')
0150          ACCEPT 302, ANST
0151          CALL PLOT (27,12,4)
0152          IF (ANST.EQ.AY) GO TO 98
0154          TYPE 313
0155     313  FORMAT (5X,'ENTER NUMBER OF TABLE ENTRIES')
0156          ACCEPT 311, NPTH
0157          TYPE 314, NPTH
0158     314  FORMAT (5X,'ENTER PRESSURE, IMPETUS,COVOLUME'/
             1 5X,'FLAME TEMP AND SPECIFIC HEAT',2X,I1,2X,'ENTRIES')
0159          DO 44 I = 1,NPTH
0160      44  ACCEPT 304, PX(I), FX(I), ETX(I), XMWX(I), GAMX(I)
0161          RU1 = 1544.*1.0
0162          RU2 = RU1/778.
0163          XMWX1 = RU1*XMWX(1)/FX(1)
0164          GAM1 = RU2/(XMWX1*GAMX(1)) + 1.0
0165          GO TO 97
```

```
98    TYPE 323, F1
323   FORMAT (5X,'PROPELLANT IMPETUS',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) F1 = TEMP
      TYPE 324, ET1
```

```
 324  FORMAT (5X,'PROPELLANT COVOLUME',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) ET1 = TEMP
      TEMP1 = XMWX1
      TEMP2 = GAM1
      TYPE 325, XMWX1
 325  FORMAT (5X,'FLAME TEMP',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) XMWX1 = TEMP
      TYPE 326, GAM1
 326  FORMAT (5X,'SPECIFIC HEAT',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) GAM1 = TEMP
      TEMP1 = XMWX1
      TEMP2 = GAM1
      IF (XMWX1.LT.1000.) TEMP1 = F1*XMWX1/(1544.*1.8)
      TEMP3 = XMWX1
      IF (XMWX1.GT.1000.) TEMP3 = 1544.*1.8*XMWX1/F1
      IF (GAM1.GE.1.0) TEMP2 = 1544.*1.8/778./TEMP3/(GAM1 - 1.)
      NPTH = 4
      P2 = 1.0
      DO 447 I = 1,4
      PX(I) = P2
      FX(I) = F1
      ETX(I) = ET1
      XMWX(I) = TEMP1
      GAMX(I) = TEMP2
      P2 = P2 + 1.0
  447 CONTINUE
      RU1 = 1544.*1.8
      RU2 = RU1/778.
      XMWX1 = RU1*TEMP1/FX(1)
      GAM1 = RU2/(XMWX1*TEMP2) + 1.0
   97 IDFF = 0
      IF (FFID.EQ.P1) IDFF = 1
      IF (FFID.EQ.P7) IDFF = 2
      IF (FFID.EQ.P19) IDFF = 3
      IF (FFID.EQ.SP) IDFF = 4
      IF (FFID.EQ.CY) IDFF = 5
      IF (IDFF.NE.0) GO TO 21
      CALL PLOT (27,12,4)
      TYPE 315
 315  FORMAT (5X,'UNKNOWN GRAIN TYPE'/
     1 5X,'INPUT TABLE OF DISTANCE BURNT'/
     2 5X,'VERSUS TOTAL BURN AREA OF CHARGE'/
     3 5X,'FIRST ENTER NUMBER OF POINTS'/
     4 5X,'TWO DIGIT NUMBER - PLEASE')
      ACCEPT 316, NPA
 316  FORMAT (I2)
      TYPE 317, NPA
 317  FORMAT (5X,'INPUT',2X,I2,2X,'ENTRIES OF TABLE'/
     15X,'DIST BURNT - TOTAL BURN AREA')
```

```
      DO 43 I = 1,NPA
   43 ACCEPT 304, WEBX(I), ABX(I)
      GO TO 22
   21 TYPE 318, GL
  318 FORMAT (5X,'GRAIN LENGTH',F12.5)
```

```
0236          ACCEPT 304, TEMP
0237          IF (TEMP.NE.0.0) GL = TEMP
0239          TYPE 319, OD
0240     319  FORMAT (5X,'GRAIN OUTER DIAMETER',F12.5)
0241          ACCEPT 304, TEMP
0242          IF (TEMP.NE.0.0) OD = TEMP
0244          TYPE 320, PD
0245     320  FORMAT (5X,'PERFORATION DIAMETER',F12.5)
0246          ACCEPT 304, TEMP
0247          IF (TEMP.NE.0.0) PD = TEMP
       C      CALL PLOT(27,12,4)
0249          TYPE 321, WID
0250     321  FORMAT (5X,'INNER WEB',F12.5)
0251          ACCEPT 304, TEMP
0252          IF (TEMP.NE.0.0) WID = TEMP
0254          TYPE 322, WOD
0255     322  FORMAT (5X,'OUTER WEB',F12.5)
0256          ACCEPT 304, TEMP
0257          IF (TEMP.NE.0.0) WOD = TEMP
0259      22  TYPE 427, FRAC
0260     427  FORMAT (5X,'IGNITION BRNT FRACT',F12.5)
0261          ACCEPT 304, TEMP
0262          IF (TEMP.NE.0.0) FRAC = TEMP
0264          CALL PLOT(27,12,4)
0265          TYPE 887, PLO
0266     887  FORMAT (5X,'LOWER FIT LIMIT',F12.5)
0267          ACCEPT 304, TEMP
0268          IF (TEMP.NE.0.0) PLO = TEMP
0270          TYPE 888, PHI
0271     888  FORMAT (5X,'UPPER FIT LIMIT',F12.5)
0272          ACCEPT 304, TEMP
0273          IF (TEMP.NE.0.0) PHI = TEMP
0275          TYPE 531, WDEV
0276     531  FORMAT (5X,'WEB DEVIATION IS',F12.5)
0277          ACCEPT 304, TEMP
0278          IF (TEMP.NE.0.0) WDEV = TEMP
0280          TYPE 532, TDEV
0281     532  FORMAT (5X,'IGNITION DEVIATION IS',F12.5)
0282          ACCEPT 304, TEMP
0283          IF (TEMP.NE.0.0) TDEV = TEMP
0285          SPACE1(10) = 0.0
0286          TYPE 2468, SPACE1(10)
0287    2468  FORMAT (5X,'VENT AREA FOR VENTED OPERATION',F12.5)
0288          ACCEPT 2469, TEMP
0289    2469  FORMAT (E12.0)
0290          IF (TEMP.NE.0.0) SPACE1(10) = TEMP
0292          TYPE 5832, PBLOW
0293    5832  FORMAT (5X,'BLOW OUT PRESSURE LEVEL',F12.5)
0294          ACCEPT 2469, TEMP
0295          IF (TEMP.NE.0.0) PBLOW = TEMP
0297          TYPE 7354, IBUG
0298    7354  FORMAT (5X,'DIFEQ TRACE CONTROL'/
```

```
     1 5X,'TYPE ''1'' FOR TRACE ON',I3)
       ACCEPT 7355, IBUG
  7355 FORMAT (I1)
       GO TO 92
    99 CONTINUE
```

```
0303          IDFF = 0
0304          IF (FFID.EQ.P1) IDFF = 1
0306          IF (FFID.EQ.P7) IDFF = 2
0308          IF (FFID.EQ.P19) IDFF = 3
0310          IF (FFID.EQ.SP) IDFF = 4
0312          IF (FFID.EQ.CY) IDFF = 5
0314          IF (IDFF.NE.0) GO TO 87
0316          TYPE 86
0317     86   FORMAT (5X,'UNKNOWN GRAIN TYPE IN STANDARD'/
             1 5X,'PROGRAM HAS ABORTED')
0318          STOP
0319     87   CONTINUE
0320          NPTH = 4
0321          TEMP1 = XMWX1
0322          TEMP2 = GAM1
0323          IF (GAM1.GE.1.0) TEMP2 = 1544.*1.8/778./XMWX1/(GAM1 - 1.)
0325          IF (XMWX1.LT.1000.) TEMP1 = F1*XMWX1/(1544.*1.8)
0327          P2 = 1.0
0328          DO 47 I = 1,4
0329          PX(I) = P2
0330          FX(I) = F1
0331          ETX(I) = ET1
0332          XMWX(I) = TEMP1
0333          GAMX(I) = TEMP2
0334          P2 = P2 + 1.0
0335     47   CONTINUE
0336     92   ISK1 = MAX0(ISK1,1)
0337          IF (IDFF.EQ.2.OR.IDFF.EQ.3) GO TO 6138
0339          WMIN = AMIN1 (WID,WOD)
0340          WOD = WMIN
0341          WID = WMIN
0342   6138   CONTINUE
0343          ISK = 10
0344          ISK2 = 5
0345          RHO = RHOC*.0361111
0346          RETURN
0347          END
```

```
      SUBROUTINE HTLOSS
C     SUBROUTINE TO CALCULATE HEAT LOSS NUMBER - 2 OPTIONS
      COMMON RUNID(5),RTITLE(10),DATE(3),OPERN(5),PROPN(10),
     1 PSORCE(10),PRLOT(10),PREM(10),TIGNR(10),GAGE(10),
     2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
     3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
     4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
     5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
     6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
     7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
     8 CON1,CON9,MEM3,MEM7,SFAC,L9,P,DP,TSTOP,I9,
     9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW
      EQUIVALENCE (FAID,SPACE1(12)),(TAID,SPACE1(13)),
     1 (XMA,SPACE1(14)),(CAID,SPACE1(15))
      MEM2 = 1
      CALL FIND1 (PMAX,F,PX,FX,NPTH,MEM2)
      CALL FIND1 (PMAX,ETA,PX,ETX,NPTH,MEM2)
      CALL FIND1 (PMAX,TZP,PX,XMWX,NPTH,MEM2)
      CALL FIND1 (PMAX,CVP,PX,GAMX,NPTH,MEM2)
      RU = 1544.*12.*1.8
      XMW = RU*TZP/(12.*F)
      TZERO = TZP
      TA = 298.
      TI = 12.*PCORR*XMI/RU
      VOL = BVOL/(2.54**3)
      CA = 14.7*VOL*29./(298.*RU)
      CI = WGHTI/454.
      CP = CHGWT/454.
      CST = CA + CI
      ETX(20) = CA/29. + CI/XMI + CAID*FRAC/XMA
      TM = CA*298. + CI*TI + CAID*FRAC*TAID
      ETX(19) = CVP*(CST + FRAC*CAID)
      TM = TM/(CST + FRAC*CAID)
      CTOT = CA + CI + CP + CAID
      RA = RU/29.
      RI = RU/XMI
      RP = RU/XMW
      RAID = RU/XMA
      PTHEO = (CA*RA*298. + CI*RI*TI + CP*RP*TZERO + CAID*RAID*TAID)
     1  /(VOL - CTOT*ETA)/1000.
      TM = TM*PMAX/PTHEO
      TL = TI*PMAX/PTHEO
      TL1 = TAID*PMAX/PTHEO
      PIGN = (CA*TA/29. + CI*TL/XMI + FRAC*CAID*TL1/XMA)*RU/(VOL -
     1 (CST + FRAC*CAID)*ETA - CP/RHO - (1. - FRAC)*CAID/RHO)/1000.
      CALL FINDTP (PIGN, TIGN,3,2,1,2,NPMA,MEM2,MZ)
      CON9 = VOL - CP/RHO - (1. - FRAC)*CAID/RHO
      IF (H.EQ.0.0) GO TO  10
      IF (FRAC.EQ.1.0) RETURN
   10 DPDT = (PTHEO - PMAX)/(TMAX - TIGN)
      H = (VOL - CTOT*ETA)*CVP*DPDT/RU*1000.*CTOT/
     1 (ETX(20) + CP/XMW + (1. - FRAC)*CAID/XMA)
```

```
      IF (IHL.NE.2) GO TO 1492
      IF (FRAC.EQ.1.0) RETURN
      HTL1 = H
      GO TO 1493
 1492 SPACE1(36) = 450.
```

```
0048          TYPE 372, SPACE1(36)
0049    372   FORMAT (5X,'AVERAGE BOMB WALL TEMPERATURE',F12.5)
0050          ACCEPT 373, TEMP
0051    373   FORMAT (E12.0)
0052          IF (TEMP.NE.0.0) SPACE1(35) = TEMP
0054          HB = H*1000./SPACE2(2)/((TZERO*PMAX/PTHEO + TM)/2.
             1 - SPACE1(36))
0055          WB = ((1. - FRAC)*CAID + CP)/(TMAX - TIGN)*1000.
0056          WB = WB**0.8
0057          H = HB/WB
0058          TYPE 932, HB, H
0059    932   FORMAT (2E16.6)
0060          SPACE1(34) = 0.0
0061    1493  IF (FRAC.EQ.1.0) GO TO 68
0063          TST = TIGN - 0.50
0064          TST = AMAX1(TST,0.0)
0065          SUM = 0.0
0066          DELT = 0.025
0067          DO 69 I = 1,20
0068          CALL FINDTP (TST,DP,3,1,3,2,NPMA,MEM2,MZ)
0069          SUM = SUM + DP
0070          TST = TST + DELT
0071     69   CONTINUE
0072          DPB = SUM*50.
0073          PIG = PIGN*1000.
0074          DYN = FRAC*CAID/TIGN*1000.
0075          DYNL = DYN
0076          TSYS = (CON9 - (FRAC*CAID + CST)*ETA)*PIG/ETX(20)/RU
0077    1490  DYN = DYN**0.8
0078          HTL = HTL1
0079          IF (IHL.EQ.2) GO TO 1494
0081          HTL = H*DYN*SPACE2(2)*(TSYS - 298.)/1000.
0082    1494  CONTINUE
0083          DYN = ((CON9 - (FRAC*CAID + CST)*ETA)*DPB + ETX(20)*RU*HTL/
             1 ETX(19))/(ETX(20)*RU*(TAID - TSYS)/(CST + FRAC*CAID) +
             2 RU*TSYS/XMA - PIG/RHO + PIG*ETA)
0084          IF (ABS (1. - DYN/DYNL) - 0.001) 310,310,311
0085    311   DYNL = DYN
0086          GO TO 1490
0087    310   CONTINUE
0088          XNIGN = 0.0
0089          TYPE 1510, XNIGN
0090    1510  FORMAT (5X,'POWER ON IGNITER FLOW',F12.5)
0091          ACCEPT 1511, TEMP
0092    1511  FORMAT (E12.0)
0093          IF (TEMP.NE.0.0) XNIGN = TEMP
0095          SPACE1(33) = XNIGN
0096          PB = PIG**XNIGN
0097          SPACE1(34) = DYN/PB
0098          TYPE 1496, SPACE1(34)
0099    1496  FORMAT (E16.6)
0100     68   CONTINUE
```

```
      RETURN
      END
```

```
0001        SUBROUTINE HTFIT
      C     SUBROUTINE TO FIT DECAY TO FIND HEAT LOSS COEFFICIENT
0002        COMMON RUNID(5),RTITLE(10),DATE(3),OPERN(5),PROPN(10),
           1 PSORCE(10),PRLOT(10),PREM(10),TIGNR(10),GAGE(10),
           2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
           3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
           4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
           5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
           6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
           7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
           8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
           9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW
0003        COMMON /GENE/ WIDP(5),WODP(5),UCR(5),SFAC(5,5),TDEL(5),
           1 WDEV,TDEV,TUST
0004        COMMON /BLAH/ PLO, PHI, ACO, XMC
0005        DIMENSION A1(500,1),B1(500,1),D1(1,1)
0006     20 MEM2 = 1
0007        MEM3 = 1
0008        NE = NPMA + 50/ISK1
0009        INOT = (KTOT - NE)/500 + 1
0010        CTOT = CST + CP
0011        RU = 12.*1544.*1.8
0012        CALL FIND1 (PMAX, F, PX, FX, NPTH, MEM2)
0013        CALL FIND1 (PMAX, TZP, PX, XMWX, NPTH, MEM2)
0014        CALL FIND1 (PMAX, CVP, PX, GAMX, NPTH, MEM2)
0015        XMW = RU*TZP/(12.*F)
0016        BOT = (ETX(20) + CP/XMW)*RU
0017     44 J = 0
0018        DO 62 I = NE,KTOT,INOT
0019        READ (2'I) TI, P, DP
0020        CALL FIND1 (P, ETA, PX, ETX, NPTH, MEM2)
0021        DETA = (ETX(MEM2+1) - ETX(MEM2))/(PX(MEM2+1) -
           1 PX(MEM2))
0022        P = P*1000.
0023        DP = DP*1000.
0024        DETA = DETA/1000.
0025        T = P*(VOL - CTOT*ETA)/BOT
0026        J = J + 1
0027        A1(J,1) = T**4
0028        B1(J,1) = -DP*(VOL - CTOT*ETA - CTOT*DETA*P)*CVP/RU*1000.
           1 *CTOT/(ETX(20) + CP/XMW)
0029     62 CONTINUE
0030        CALL SIMEQ (A1,B1,D1,J,1,1)
0031        SPACE2(3) = D1(1,1)/SPACE2(2)
0032        SUM = 0.0
0033        DO 777 I7 = 1,J
0034    777 SUM = SUM + B1(J,1)**2
0035        RMS = SQRT(SUM/(J - 1))
0036        WB = (CP/(TMAX - TIGN))*1000.
0037        WB = WB**0.8
0038        TAV = (TZERO**4 + TM**4)/2.
0039        TGOO = (TZERO + TM)/2. - SPACE1(36)
```

```
HL = H*WB*TGOO - SPACE2(3)*TAV
SUM1 = 0.0
SUM2 = 0.0
DELT7 = (TMAX - TIGN)/1000.
T7 = TIGN
```

```
0045   836  CALL FINDTP(T7,DPT,3,1,3,2,3000,MEM2)
0046        SUM1 = SUM1 + DPT*DELT7
0047        DPT = AMAX1(DPT,0.00001)
0048        SUM2 = SUM2 + DELT7*DPT**0.8
0049        T7 = T7 + DELT7
0050        IF (T7.LE.TMAX) GO TO 836
0052        FAC7 = SUM1**0.8/SUM2
0053        H = HL/W0/TGOO
        C   H = H*FAC7
0054        TYPE 100, D1(1,1), SPACE2(3), RMS, H
0055   100  FORMAT (4E15.5)
0056        RETURN
0057        END
```

```
0001          SUBROUTINE SUMUP
        C     SUBROUTINE TO PRINT SUMMARY SHEET OF ANALYSIS
0002          COMMON RUNID(5),RTITLE(18),DATE(3),OPERN(5),PROPN(18),
            1 PSORCE(18),PRLOT(18),PREM(18),TIGNR(18),GAGE(18),
            2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
            3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
            4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
            5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
            6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
            7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
            8 CON1,CON9,MEM3,MEM7,SFAC,L9,P,DP,TSTOP,I9,
            9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW
0003          DIMENSION ABC (5)
0004          DATA ABC/'CONS','TANT','PROP','ORTI','ONAL'/
0005          PRINT 100
0006     100  FORMAT (1H1///)
0007          PRINT 101, (RUNID(I), I = 1,5)
0008     101  FORMAT (10X,'RUN ID:'29X,5A4)
0009          PRINT 102, (RTITLE(I),I = 1,18)
0010     102  FORMAT (10X,'RUN TITLE:',25X,18A4)
0011          PRINT 103, (DATE(I), I = 1,3)
0012     103  FORMAT (10X,'DATE:',30X,3A4)
0013          PRINT 104, (OPERN(I), I = 1,5)
0014     104  FORMAT (10X,'OPERATOR:',26X,5A4/)
0015          PRINT 105
0016     105  FORMAT (10X,'PROPELLANT DATA:'/)
0017          PRINT 106, (PROPN(I), I = 1,18)
0018     106  FORMAT (10X,'TYPE:',30X,18A4)
0019          PRINT 107, CHGWT
0020     107  FORMAT (10X,'WEIGHT (GMS):',22X,F12.5)
0021          PRINT 108, RHOC
0022     108  FORMAT (10X,'DENSITY (GM/CC):',19X,F12.5)
0023          PRINT 109, PTEMP
0024     109  FORMAT (10X,'INITIAL TEMPERATURE (DEG K):',7X,F12.5)
0025          PRINT 110, (PRLOT(I), I = 1,18)
0026     110  FORMAT (10X,'LOT:',31X,18A4)
0027          PRINT 111, (PSORCE(I), I = 1,18)
0028     111  FORMAT (10X,'SOURCE:',28X,18A4)
0029          PRINT 112, FFID
0030     112  FORMAT (10X,'GRAIN TYPE:',24X,A4)
0031          PRINT 113, GL, OD, PD
0032     113  FORMAT (10X,'LENGTH,OD,ID (IN):',17X,3(F12.5,','))
0033          PRINT 114, WID, WOD
0034     114  FORMAT (10X,'INNER WEB,OUTER WEB (IN):',10X,2(F12.5,','))
0035          PRINT 115, FX(1)
0036     115  FORMAT (10X,'THEORETICAL IMPETUS (FT-LB/LB):',4X,F12.5)
0037          PRINT 116, TZERO
0038     116  FORMAT (10X,'FLAME TEMPERATURE:',17X,F12.5)
0039          PRINT 117, XMWX1
0040     117  FORMAT (10X,'AVERAGE MOLECULAR WEIGHT OF PROD:',2X,F12.5)
0041          PRINT 118, ETX(1)
0042     118  FORMAT (10X,'CO-VOLUME (CU IN/LB):',14X,F12.5)
```

```
      PRINT 119, GAM1
119   FORMAT (10X,'GAMMA (RATIO OF SP HTS):'11X,F12.5)
      PRINT 120, (PREM(I), I = 1,18)
120   FORMAT (10X,'REMARKS:',27X,18A4/)
      PRINT 121
```

```
121   FORMAT (10X,'IGNITER DATA:'/)
      PRINT 122, (TIGNR(I), I = 1,18)
122   FORMAT (10X,'TYPE:',30X,18A4)
      PRINT 123, WGHTI
123   FORMAT (10X,'WEIGHT (GMS):',22X,F12.5)
      PRINT 124, PCORR
124   FORMAT (10X,'IMPETUS (FT-LB/LB):',16X,F12.5/)
      PRINT 125
125   FORMAT (10X,'EQUIPMENT DATA'/)
      PRINT 126, BVOL
126   FORMAT (10X,'BOMB VOLUME (CC):',18X,F12.5)
      PRINT 127, BTEMP
127   FORMAT (10X,'BOMB TEMP (DEG K):'17X,F12.5)
      PRINT 128, (GAGE(I), I = 1,18)
128   FORMAT (10X,'GAUGE TYPE:',24X,18A4)
      PRINT 129,SCAL
129   FORMAT (10X,'CALIBRATION FACTOR (PC/PSI):',7X,F12.5/)
      PRINT 130
130   FORMAT (10X,'RESULTS:'/)
      PRINT 131, PTHEO
131   FORMAT (10X,'THEORETICAL MAX PRESS (KPSIA):',5X,F12.5)
      PRINT 132, PMAX
132   FORMAT (10X,'OBSERVED MAX PRESS (KPSIA):', 8X,F12.5)
      PRINT 133, PIGN
133   FORMAT (10X,'IGNITER PRESSURE (KPSIA):',10X,F12.5)
      PRINT 134
134   FORMAT (/10X,'IGNITION TIME INFORMATION:' )
      PRINT 135, T10
135   FORMAT (10X,'TIME TO 10% PMAX (MSEC):',11X,F12.5)
      PRINT 136, T90
136   FORMAT (10X,'TIME TO 90% PMAX (MSEC):',11X,F12.5)
      PRINT 137, TMAX
137   FORMAT (10X,'TIME TO 100% PMAX (MSEC):',10X,F12.5)
      PRINT 138, T1090
138   FORMAT (10X,'TIME FROM 10% TO 90% PMAX (MSEC):',2X,F12.5)
      PRINT 140
140   FORMAT (1H1////10X,         'QUICKNESS INFORMATION:'/)
      PRINT 141, DP9(1)
141   FORMAT (10X,'PDOT AT .250 PMAX:',5X,F12.5)
      PRINT 142, DP9(2)
142   FORMAT (10X,'PDOT AT .375 PMAX:',5X,F12.5)
      PRINT 143, DP9(3)
143   FORMAT (10X,'PDOT AT .500 PMAX:',5X,F12.5)
      PRINT  144, DP9(4)
144   FORMAT (10X,'PDOT AT .625 PMAX:',5X,F12.5)
      PRINT 145, DP9(5)
145   FORMAT (10X,'AVERAGE PDOT:',10X,F12.5/)
      PRINT 139, DPMAX, PPM
139   FORMAT (10X,'MAXIMUM PDOT (MPSI/SEC):',F11.5,5X,'OBSERVED AT',
     1 ' P = (KPSIA):',F12.5/)
      GO TO (1,2), IHL
2     PRINT 146, (ABC(I), I = 1,2)
```

```
  146 FORMAT (10X,'HEAT LOSS OPTION:',2X,2A4)
      GO TO 3
    1 PRINT 147, (ABC (I), I = 3,5)
  147 FORMAT (10X,'HEAT LOSS OPTION:',2X,3A4)
    3 PRINT 148, H
```

```
0104   140  FORMAT (10X,'HEAT LOSS NUMBER:',F14.7)
0105        RETURN
0106        END
```

```
RT-11 FORTRAN IV        V01-11  SOURCE LISTING          PAGE 001

0001         SUBROUTINE REDUCE
        C    DRIVER FOR DIFFERENTIAL EQUATION SOLVER
0002         COMMON RUNID(5),RTITLE(10),DATE(3),OPERN(5),PROPN(10),
            1 PSORCE(10),PRLOT(10),PREM(10),TIGNR(10),GAGE(10),
            2 SPACE1(36),CHGWT,WID,PTEMP,WGHT1,PCORR,BVOL,BTEMP,
            3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
            4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
            5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
            6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
            7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
            8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
            9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW
0003         COMMON /GENE/ WIDP(5),WODP(5),UCR(5),SFAC(5,5),TDEL(5),
            1 WDEV,TDEV,TWST
0004         DIMENSION TPRNT(2)
0005         TPRNT(1) =- STIME*1.0E-03
0006         TPRNT(2) = 10000.
0007         TSTOP = TMAX
0008         IF (SPACE1(10).NE.0.0) TMAX = 2900*STIME*1.0E-03
0010         IF (SPACE1(10).NE.0.0) H = 0.0
0012         JDO = 5
0013         IF (TDEV.EQ.0.0) JDO = 1
0015         JDO = JDO + 7
0016         CALL EVES (JDO, TPRNT)
0017         ENDFILE 2
0018         ENDFILE 6
0019         RETURN
0020         END
```

```
0001        SUBROUTINE SETUP (T, Y, SIG, N)
0002        COMMON RUNID(5),RTITLE(10),DATE(3),OPERN(5),PROPN(10),
           1 PSORCE(10),PRLOT(10),PREM(10),TIGNR(10),GAGE(10),
           2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
           3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
           4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
           5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
           6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
           7 ISK,ISK2,MEM2,XM1,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
           8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
           9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW,RATE,RL
0003        COMMON /GENE/ WIDP(5),WODP(5),UCR(5),SFAC(5,5),TDEL(5),
           1 WDEV,TDEV,TUST
0004        COMMON /KEVIN/ TE(35), XT(35)
0005        DIMENSION JD(2)
0006        EQUIVALENCE (JD(1),SPACE1(35)),(CAID,SPACE1(15)),
           1 (CPGM2,SPACE1(16)),(PBLOW,SPACE1(11))
0007        DIMENSION T(2), Y(2), SIG(12,3)
0008        DIMENSION CPRO(5),PRO(5),DDW(5)
0009        DATA PRO/.1,.2,.4,.2,.1/,DDW/-1.17741,-.83255,.0,.83255,1.17741/
0010        MEM2 = 1
0011        MEM3 = 1
0012        CI = WGHTI/454.
0013        CALL FIND1 (PMAX,F,PX,FX,NPTH,MEM2)
0014        CPGM2 = GAM1*(2./(GAM1 + 1.))**((GAM1 + 1.)/(GAM1 - 1.))
0015        ABX(20) = 1.0E+05
0016        MEM7 = 1
0017        JD(1) = 5
0018        JD(2) = 5
0019        IF (TDEV.EQ.0.0) JD(1) = 1
0021        IF (WDEV.EQ.0.0) JD(2) = 1
0023        CON9 = VOL - (CHGWT/454. + CAID)/RHO
0024        IF (IDFF.EQ.0) GO TO 10
0025        I9 = 0
0027        SZERO = 0.0
0028        SUM9 = 0.0
0029        JDO = JD(1)
0030        DO 75 J = 1,JDO
0031        J1 = J + 7
0032        SIG (J1,2) = 0.001
0033        SIG (J1,3) = 1.0E+05
0034        CPART = CP*PRO(J)
0035        IF (JDO.EQ.1) CPART = CP
0037        IDO = JD(2)
0038        DO 76 I = 1,IDO
0039        CPRO(I) = CPART*PRO(I)
0040        IF (IDO.EQ.1) CPRO(I) = CPART
0042        WIDP(I) = WID + DDW(I)*WDEV
0043        WODP(I) = WOD - DDW(I)*WDEV
0044        I9 = 0
0045        GO TO (1,2,3,4,5), IDFF
0046    1     CALL FORM1(0.0, I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
```

```
      GO TO 39
2       CALL FORM7(0.0,I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
      GO TO 39
3       CALL FORM19(0.0,I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
      GO TO 39
```

```
 4      CALL FORMSP(0.0,I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
      GO TO 39
 5      CALL FORMCY(0.0,I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
39    SFAC(J,I) = CPRO(I)/(RHO*V0)
      SUM9 = SUM9 + SFAC(J,I)
      SZERO = SZERO + SFAC(J,I)*S
      SIG(J1,3) = AMIN1 (SIG(J1,3), UCR(I))
 76   CONTINUE
      TDEL(J) = DDW(J)*TDEV
      IF (J.EQ.1) TDS = TDEL(J)
      TDEL(J) = TDEL(J) - TDS
 75   CONTINUE
 10     CONTINUE
      IF (IDO.EQ.1) GO TO 723
      DO 723 I = 1,4
      K = I + 1
      DO 723 J = K,5
      IF (UCR(J).GE.UCR(I)) GO TO 723
      A1 = UCR(I)
      A2 = WIDP(I)
      A3 = WODP(I)
      DO 724 L = 1,5
      A4 = SFAC(L,I)
      SFAC(L,I) = SFAC(L,J)
      SFAC (L,J) = A4
 724  CONTINUE
      UCR(I) = UCR(J)
      WIDP(I) = WIDP(J)
      WODP(I) = WODP(J)
      UCR(J) = A1
      WIDP(J) = A2
      WODP(J) = A3
723   CONTINUE
      L9 = 0
      T(1) = TIGN
      IF (IDFF.EQ.0) UCR(1) = WEBX(NPA)
      IF (IDFF.EQ.0) UCR(2) = WEBX(NPA)
      IF (IDFF.EQ.0) UCR(3) = WEBX(NPA)
      IF (IDFF.EQ.0) UCR(4) = WEBX(NPA)
      IF (IDFF.EQ.0) UCR(5) = WEBX(NPA)
      IF (IDFF.EQ.0) SZERO = ABX(1)
      NUMB = SUM9
      IF (IDFF.EQ.0) NUMB = 1
      PRINT 100, SZERO, NUMB
100   FORMAT (/10X,'INITIAL SURFACE AREA (SQ IN):',F12.5/
     1 10X,'NUMBER OF GRAINS:',16X,I8)
      Y(1) = CST - WGHTI/454.
      Y(2) = WGHTI/454.
      Y(3) = FRAC*CAID
      Y(4) = 0.0
      Y(5) = Y(3)
      Y(6) = 0.0
```

```
      Y(7) = PIGN
      SIG(1,2) = 0.0001
      SIG(2,2) = 0.0001
      SIG(3,2) = 0.0001
      SIG(4,2) = 0.001
```

```
      SIG(5,2) = 0.0001
      SIG(5,3) = CAID
      SIG(6,2) = 0.001
      SIG(7,3) = PBLOW
      SPACE1(31) = 0.0
      IF (IHL.EQ.2) RETURN
      DN = (WGHTI/454. + FRAC*CAID)/TIGN*1000.
      G = H*DN**0.8
      CALL WALTEM (G,T(1),298.,TM)
      CALL WALTEM (G, T(1),298.,TM)
      SFAZ = TM
      DO 1729 I7 = 1,35
 1729 TE(I7) = XT(I7)
      RETURN
      END
```

```
      SUBROUTINE DIFEQ (T, Y, DY, N, TPR)
      COMMON RUNID(5),RTITLE(18),DATE(3),OPERN(5),PROPN(18),
     1 PSORCE(18),PRLOT(18),PREM(18),TIGNR(18),GAGE(18),
     2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
     3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
     4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
     5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
     6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
     7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
     8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
     9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW,RATE,RL
      EQUIVALENCE (IMUD(1),SPACE2(4)),(IBUG,IMUD(2))
      DIMENSION IMUD(2)
      COMMON /GENE/ WIDP(5),WODP(5),UCR(5),SFAC(5,5),TDEL(5),
     1 WDEV,TDEV,TUST
      COMMON /KEVIN/ TE(35), XT(35)
      DIMENSION T(2), Y(2), DY(2),TPR(2)
      DIMENSION ARATJ(5)
      DIMENSION JD(2)
      EQUIVALENCE (JD(1),SPACE1(35)),(TAID,SPACE1(13)),
     1 (XMA,SPACE1(14)),(CPGM2,SPACE1(16))
      CALL FINDTP (T(1),P,3,1,2,2,3000,MEM3, MZ)
      CALL FINDTP (T(1),DP,3,1,3,2,3000,MEM3, MZ)
      CALL FIND1 (P, ETA, PX, ETX, NPTH, MEM2)
      CALL FIND1 (P, F, PX, FX, NPTH, MEM2)
      CALL FIND1 (P, TZP, PX, XMWX, NPTH, MEM2)
      CALL FIND1 (P, CVP, PX, GAMX, NPTH, MEM2)
      RU = 1544.*1.8
      TI = PCORR*XMI/RU
      XMW = RU*TZP/F
      JDO = JD(1)
      IDO = JD(2)
      DETA = (ETX(MEM2+1) - ETX(MEM2))/(PX(MEM2+1) - PX(MEM2))
      DIMP = (FX(MEM2+1) - FX(MEM2))/(PX(MEM2+1) - PX(MEM2))
      DCVP = (GAMX(MEM2+1) - GAMX(MEM2))/(PX(MEM2+1) - PX(MEM2))
      DTZP = (XMWX(MEM2+1) - XMWX(MEM2))/(PX(MEM2+1) - PX(MEM2))
      DXMP = RU*(DTZP/F - TZP*DIMP/(F**2))
      P = P*1000.
      DP = DP*1000.
      XT1 = 10000.
      DY1 = DY(5) + DY(6)
      DN = AMAX1 (DY1*1000., 0.000001)
      DETA = DETA/1000.*DP
      DIMP = DIMP/1000.*DP
      DCVP = DCVP/1000.*DP
      DTZP = DTZP/1000.*DP
      DXMP = DXMP/1000.*DP
      IF (IDFF.NE.0) GO TO 10
      CALL FIND1 (Y(8),AB,WEBX,ABX,NPA,MEM7)
      GO TO 40
   10 AAB = 0.0
      WIP = 0.0
```

```
DELJ = TIGN
TDLJ = 0.0
DELI = ABX(20)
DO 75 J = 1,JDO
J1 = J + 7
```

```
      ARATJ(J) = 1.0
      ARATI = 1.0
      IF (J.EQ.1) GO TO 1978
      IF (TDEL(J).EQ.TDLJ) GO TO 1978
      ARATJ(J) = (T(1) - DELJ)/(TDEL(J) - TDLJ)
      ARATJ(J) = AMIN1 (AMAX1(ARATJ(J),0.0), 1.0)
      ARATI = (T(1) - DELI)/(TDEL(J) - TDLJ)
      ARATI = AMIN1 (AMAX1(ARATI,0.0),1.0)
      ARATI = 1.0 - ARATI
 1978 CONTINUE
      AB = 0.0
      ARATK = 1.0
      UCRI = UCR(1)
      DO 76 I = 1,IDQ
      IF (UCR(1).EQ.UCRI) GO TO 486
      ARATK = (Y(J1) - UCRI)/(UCR(I) - UCRI)
      ARATK = AMIN1 (AMAX1 (ARATK, 0.0), 1.0)
      ARATK = 1.0 - ARATK
  486 CONTINUE
      GO TO (1,2,3,4,5), IDFF
 1    CALL FORM1(Y(J1),I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
      GO TO 39
 2    CALL FORM7(Y(J1),I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
      GO TO 39
 3    CALL FORM19 (Y(J1),I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
      GO TO 39
 4    CALL FORMSP (Y(J1),I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
      GO TO 39
 5    CALL FORMCY (Y(J1),I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
   39 CONTINUE
      AB = AB + SFAC(J,I)*S*ARATK
      UCRI = UCR(I)
   76 CONTINUE
      AAB = AAB + AB*ARATJ(J)*ARATI
      DELJ = TIGN + TDEL(J)
      DELI = ABX(20) + TDEL(J)
      TDLJ = TDEL(J)
   75 CONTINUE
   40 CONTINUE
      WSYS = Y(1) + Y(2) + Y(3) + Y(4)
      VSYS = CON9 + (Y(5) + Y(6))/RHO - WSYS*ETA
      TOTMOL = Y(1)/29. + Y(2)/XMI + Y(3)/XMR + Y(4)/XMW
      RU = 1544.*1.8
      RSYS = RU*TOTMOL/WSYS
      TSYS = P*VSYS/(12.*RSYS*WSYS)
      IF (IBUG.EQ.0) GO TO 7354
      TYPE 2936, TSYS,P,VSYS,RSYS,WSYS
 2936 FORMAT (5E14.5)
 7354 CONTINUE
      CSTAR = SQRT(32.174*RSYS*TSYS/CPGM2)
      DHN = 32.174*P*SPACE1(31)/CSTAR/1000.
      GO TO (20,21), IHL
```

```
20    DO 1739 I7 = 1,35
1739  XT(I7) = TE(I7)
      G = H*DN**0.8
      CALL WALTEM (G,T(2),SFAZ,TSYS)
97    G = H*DN**0.8
```

```
0109          ARP = G*(TSYS - XT(1))/1000.*SPACE2(2)
0110          ARP = ARP + SPACE2(3)*(TSYS**4 - XT(1)**4)/1000.*
             1 SPACE2(2)
0111          GO TO 22
0112   21     ARP = H
0113   22     CONTINUE
0114          DY(1) = -Y(1)/WSYS*DNN
0115          DY(2) = -Y(2)/WSYS*DNN
0116          DY(5) = SPACE1(34)*P**SPACE1(33)
0117          DY(3) = DY(5) - Y(3)/WSYS*DNN
0118          RWT = DY(1) + DY(2) + DY(3) - Y(4)/WSYS*DNN
0119          RMOL = DY(1)/29. + DY(2)/XMI + DY(3)/XMA - Y(4)/WSYS*DNN/XMW
             1 -Y(4)*DXMP/(XMW**2)
0120          DY(6) = (TSYS*RWT - TAID*DY(5) + WSYS*TSYS*DCVP/CVP
             1 + ARP/CVP + GAM1*TSYS*DNN + P/(12.*RSYS)
             2 *(DY(5)/RHO - WSYS*DETA - ETA*RWT + VSYS*DP/P - VSYS/
             3 WSYS*(RU/RSYS*(RMOL
             4 - TOTMOL*RWT/WSYS))))/(TZP - TSYS + P/(12.*RSYS)*
             5 (ETA - 1./RHO + VSYS/WSYS*(1. + RU/RSYS*(1./XMW - TOTMOL/
             6 WSYS))))
0121          DY1 = DY(5) + DY(6)
0122          DY(4) = DY(6) - Y(4)/WSYS*DNN
0123          DY(7) = DP
0124          GO TO (92,93), IHL
0125     92   IF (ABS(1. - DY1*1000./DN).LE.0.001) GO TO 94
0127          IF (DY1.LE.0.0) GO TO 93
0129          DN = DY1*1000.
0130          GO TO 97
0131     94   IF (ABS(1. - XT(1)/XT1).LE.0.0001) GO TO 93
0133          XT1 = XT(1)
0134          GO TO 20
0135    93    IF (Y(8).EQ.0.0) SZERO = AAB
0137          IF (Y(8).EQ.0.0) ZZERO = Y(6)
0139          SRAT = AAB/SZERO
0140          IF (TDEV.NE.0.0) SRAT = SRAT/10.
0142          Z = (Y(6) - ZZERO)*454./CHGWT
0143          IF (AAB.GT.0.0) GO TO 675
0145          RATE = RL
0146          GO TO 676
0147    675   RATE = DY(6)/(RHO*AAB)
0148    676   CONTINUE
0149          DO 745 I = 1,JDO
0150          J = I + 7
0151          DY(J) = RATE*ARATJ(I)
0152    745   CONTINUE
0153          RL = RATE
0154          RATE = RATE*1000.
0155          FX(20) = TSYS
0156          RETURN
0157          END
```

```
0001        SUBROUTINE PRINT (T, Y, DY, N, TPR)
0002        COMMON RUNID(5),RTITLE(18),DATE(3),OPERN(5),PROPN(18),
           1 PSORCE(18),PRLOT(18),PREM(18),TIGNR(18),GAGE(18),
           2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
           3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
           4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
           5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
           6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
           7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
           8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
           9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW,RATE,RL
0003        COMMON /GENE/ WIDP(5),WODP(5),UCR(5),SFAC(5,5),TDEL(5),
           1 WDEV,TDEV,TUST
0004        COMMON /KEVIN/ TE(35), XT(35)
0005        DIMENSION T(2), Y(2), DY(2), TPR(2)
0006        DIMENSION JD(2)
0007        EQUIVALENCE (JD(1),SPACE1(35))
0008        DATA XYZ/101000./
0009        JDO = JD(1)
0010        IF (L9.EQ.0) L6 = 0
0012        IF (L9.EQ.0) L8 = 0
0014        IF (L9.EQ.0) L7 = 0
0016        DO 1729  I7 = 1,35
0017   1729 TE(I7) = XT(I7)
0018        IF (TPR(3).EQ.5.0) SPACE1(34) = 0.0
0020        SFAZ = FX(20)
0021        ISTP = 0
0022        DO 669 I = 1,JDO
0023        J = I + 7
0024        IF (Y(J).LT.UCR(I)) GO TO 669
0026        ISTP = ISTP + 1
0027    669 CONTINUE
0028        IF (ISTP.EQ.JDO) N = 0
0030        IF (L9.EQ.0) GO TO 777
0032        XDO = JDO + 7
0033        IF (TPR(3).LT.0.0.OR.TPR(3).GT.XDO) GO TO 4936
0035        ABX(20) = T(1)
0036   4936 CONTINUE
0037        XDO = XDO + 1.0
0038        IF (TPR(3).EQ.7.0) SPACE1(31) = SPACE1(18)
0040        IF (TPR(3).NE.XDO) RETURN
0042    777 CONTINUE
0043        P = P/1000.
0044        DP = DP/1000.
0045        DIST = 2.*Y(8)
0046        DPRAT = DP/PMAX
0047        IF (MOD(L9,ISK).NE.0) GO TO 676
0049        IF (MOD(L7,40).NE.0) GO TO 677
0051        PRINT 100, (RUNID(I), I = 1,5)
0052    677 L7 = L7 + 1
0053        IF (MOD(L6,30).NE.0) GO TO 832
0055        CALL PLOT (27,12,4)
```

```
832  L6 = L6 + 1
     PRINT 101,    T(1), P, DP, RATE, Z, SRAT, DIST, DPRAT
     TYPE 302, T(1), SFAZ, XT(1)
302  FORMAT (5X, 3E15.6)
676  CONTINUE
```

```
0061          IF (MOD(L9,ISK2).NE.0) GO TO 675
0063          L8 = L8 + 1
0064          WRITE (11,384) T(1), P, DP, RATE
0065    384   FORMAT (4E13.6)
0066    675   CONTINUE
0067          T22 = T(1)
0068          L9 = L9 + 1
0069            IF (T(1).GE.TSTOP) N = 0
0071          IF (N.EQ.0) WRITE (11,384) XYZ,XYZ,XYZ,XYZ
0073          RETURN
0074    100   FORMAT (1H1/5X,5A4/7X,'TIME',6X,'PRESS',6X ,'DP/DT',8X,
                ATE',6X,'WT FR',4X,'SURF FR',4X,'WEB BRN',3X,
             2 'PDOT/PMAX'/7X,'MSEC',6X,'KPSIA',4X,'MPSI/SEC',5X,
             3 'IN/SEC',27X,'INCH',6X,'MSEC-1'/)
0075    101   FORMAT (2(4X,F7.3),4X,F8.3,4X,F7.3,3(4X,F7.4),4X,F8.3)
0076          END
```

```
      SUBROUTINE FORM1(DB,I,OD1,PD1,WID,WOD,V0,GL,S,UCRIT)
      DATA PI/3.141593/,PI4/.785399/
      W = DB*2.0
      DDW = (WOD - WID)/4.
      OD = OD1 + DDW
      PD = PD1 - DDW
      PD = AMAX1 (PD, 0.0)
      OD = AMAX1 (OD, 0.0)
      IF (I.NE.0) GO TO 10
      E = PI4*(OD**2 - PD**2)
      E = AMAX1 (E, 0.0)
      V0 = E*GL
      S = 2.*E + GL*PI*(OD + PD)
      I = I + 1
      UCRIT = (OD - PD)/2.
      RETURN
   10 UCRIT = (OD - PD)/2.
      IF (W.GT.UCRIT) GO TO 300
      OOD = OD - W
      OOD = AMAX1 (OOD, 0.0)
      PPD = PD + W
      GGL = GL - W
      E = PI4*(OOD**2 - PPD**2)
      E = AMAX1 (E,0.0)
      S = 2.*E + GGL*PI*(OOD + PPD)
      RETURN
  300 S = 0.0
      RETURN
      END
```

```
      SUBROUTINE FORM7(DB,I,D,PD,WID,WOD,V0,GL,S,CRITU)
      LOGICAL RYPE
      DATA PI,PI3,PI4/3.14159265359,1.047197551197,.7853981633975/
      DATA RT/1.7320508076/
      W = 2.*DB
      IF(I.GT.0) GOTO 10
      I = 1
      E=PI4*(D**2-7.*PD**2)
      V0 = E*GL
      V=V0
      S0=2.*E+PI*(D+7.*PD)*GL
      S=S0
      WW=PD+WID
      E=.5*(D**2-PD**2+4.*WW**2-2.*WW*D*RT)/(D+PD-WW*RT)
      CRITU=AMIN1(.5*(D-PD),AMAX1(2.*WW/RT-PD,E),GL)
      RYPE=D-WID.LT.WW*RT
      Z=0.
      RETURN
   10 E=0.
      WMIN = AMIN1 (WID,WOD)
      RYPE=D-WID.LT.WW*RT
      S=0.
      U=AMAX1(W,0.)
      GRL=GL-U
      IF(U.GT.CRITU) GOTO 300
      PRFD=PD+U
      PRFD2=PRFD**2
      OD=D-U
      OD2=OD**2
      IF(U.GT.WMIN) GOTO 100
      E=PI4*(OD2-7.*PRFD2)
      S=2.*E+PI*(OD+7.*PRFD)*GRL
      GO TO 300
  100 WW=PD+WID
      WW2=WW**2
      THETA=2.*ACOS(AMIN1(WW/PRFD,1.))
      ALPHA=ACOS(AMIN1((.25*(OD2-PRFD2)+WW2)/(WW*OD),1.))
      IF(ALPHA.GE..5*PI3) GOTO 210
      BETA=ACOS(AMAX1((.25*(PRFD2-OD2)+WW2)/(WW*PRFD),-1.))
     1 -.5*THETA - PI3
      IF(RYPE) GOTO 250
      E=3.*OD*WW*SIN(ALPHA)+1.5*(OD2*(.5*PI3-ALPHA)-WW2*RT-PRFD2*(BETA
     1 +.5*SIN(THETA)))
      S=2.*E+(6.*BETA*PRFD+(PI-6.*ALPHA)*OD)*GRL
  210 IF(THETA.GE.PI3) GOTO 300
      E1=1.5*(WW2*RT-1.5*PRFD2*(SIN(THETA)+PI3-THETA))
      E=E+E1
      S=S+2.*E1+9.*PRFD*(PI3-THETA)*GRL
      GOTO 300
  250 E=3.*WW*OD*SIN(ALPHA)+1.5*(OD2*(.5*PI3
     1 -ALPHA) -PRFD2*(SIN(THETA)
     2 +BETA+.5*(PI-THETA)))
```

```
      S=2.*E+6.*(OD*(.5*PI3-ALPHA)+PRFD*(BETA+.5*(PI-THETA)))*GRL
  300 V=E*GRL
      Z=1.-V/V0
      RETURN
      END
```

```
0001        SUBROUTINE FORM19(DB,I,D,PD,WID,WOD,V0,GL,S,CRITU)
0002        LOGICAL RYPE
0003        DATA PI,PI3,PI4/3.14159265359,1.047197551197,.7853981633975/
0004        DATA RT/1.7320508076/
0005        W = 2.*DB
0006        IF(I.GT.0) GOTO 10
0008        I = 1
0009        E=PI4*(D**2-19.*PD**2)
0010        V0=E*GL
0011        V=V0
0012        S0=2.*E+PI*(D+19.*PD)*GL
0013        S=S0
0014        WW=PD+WID
0015        E=(D+PD)**2
0016        WW2=WW**2
0017        E=.5*(D-PD-WW*SQRT(12.*(E-16.*WW2)/(E-12.*WW2)))
0018        CRITU=AMIN1(AMAX1(2.*WW/RT-PD,E),GL)
0019        RYPE=D-WID.LT.WW*SQRT(13.)
0020        IF(RYPE) GOTO 250
0022        Z=0.
0023        RETURN
0024     10 E=0.
0025        WMIN=AMIN1(WID,WOD)
0026        S=0.
0027        U=AMAX1(W,0.)
0028        GRL=GL-U
0029        IF(U.GT.CRITU) GOTO 300
0031        PRFD=PD+U
0032        PRFD2=PRFD**2
0033        OD=D-U
0034        OD2=OD**2
0035        IF(U.GT.WMIN) GOTO 100
0037        E=PI4*(OD2-19.*PRFD2)
0038        S=2.*E+PI*(OD+19.*PRFD)*GRL
0039        GOTO 300
0040    100 WW=PD+WID
0041        WW2=WW**2
0042        THETA=2.*ACOS(AMIN1(WW/PRFD,1.))
0043        ALPHA1=ACOS(AMIN1((.125*(OD2-PRFD2)+2.*WW2)/(WW*OD),1.))
0044        ALPHA2=ACOS(AMIN1((.25*(OD2-PRFD2)+3.*WW2)/(WW*OD*RT),1.))
0045        ALPHA=ALPHA1+ALPHA2
0046        IF(ALPHA.GE..5*PI3) GOTO 210
0048        BETA1=ACOS(AMAX1((.125*(PRFD2-OD2)+2.*WW2)/(WW*PRFD),-1.))
           1  -.5*THETA-PI3
0049        BETA2=ACOS(AMAX1((.25*(PRFD2-OD2)+3.*WW2)/(WW*PRFD*RT),-1.))
           1  -.5*(THETA+PI)
0050        BETA=BETA1+BETA2
0051        IF(RYPE) GOTO 250
0053        E=3.*OD*WW*(2.*SIN(ALPHA1)+RT*SIN(ALPHA2))-6.*WW2*RT+1.5*
           1  (OD2*(.5*PI3-ALPHA)-PRFD2*(SIN(THETA)+BETA))
0054        S=2.*E+6.*(OD*(.5*PI3-ALPHA)+PRFD*BETA)*GRL
0055    210 IF(THETA.GE.PI3) GOTO 300
```

```
      E1=6.*(WW2*RT-1.5*PRFD2*(SIN(THETA)+PI3-THETA))
      E=E+E1
      S=S+2.*E1+36.*PRFD*(PI3-THETA)*GRL
      GOTO 300
  250 TYPE 251
```

```
  251 FORMAT( ' GRAIN GEOMETRY YIELD' NO OUTER SLIVERS.')
      STOP
  300 V=E*GRL
      Z=1.-V/V0
      RETURN
      END
```

```
      SUBROUTINE FORMSP (DB,I,OD1,PD1,WID,WOD,V0,GL,S,UCRIT)
      DATA PI4/.785399/,PI/3.141593/
      W = DB*2.0
      DDW = (WOD - WID)/2.
      OD = OD1 + DDW
      OD = AMAX1 (OD, 0.0)
      IF (I.NE.0) GO TO 10
      I = I + 1
      R = OD/2.0
      S = 4.*PI*R**2
      V0 = 4.*PI/3.*R**3
      UCRIT = OD
      RETURN
 10   UCRIT = OD
      IF (W.GT.UCRIT) GO TO 300
      R = (OD - W)/2.
      S = 4.*PI*R**2
      RETURN
 300  S = 0.0
      RETURN
      END
```

```
      SUBROUTINE FORMCY (DB,I,OD1,PD,WID,WOD,V0,GL1,S,UCRIT)
      DATA PI4/.785398/,PI/3.141593/
      W = DB*2.0
      DDW = (WOD - WID)/2.
      OD = OD1 + DDW
      GL = GL1 + DDW
      OD = AMAX1 (OD, 0.0)
      GL = AMAX1 (GL, 0.0)
      IF (I.NE.0 ) GO TO 10
      I = I + 1
      E = PI4*OD**2
      V0 = E*GL
      S = 2.*E + PI*GL*OD
      UCRIT = AMIN1 (OD, GL)
      RETURN
 10   UCRIT = AMIN1 (OD, GL)
      IF (W.GT.UCRIT) GO TO 300
      OOD = OD - W
      GGL = GL - W
      E = PI4*OOD**2
      S = 2.*E + PI*GGL*OOD
      RETURN
 300  S = 0.0
      RETURN
      END
```

```
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0001          FUNCTION ACOS (A)
0002          DATA PI2/1.570796/, PI/3.141593/
0003          B = SQRT (1. - A**2)
0004          IF (A.NE.0.0) GO TO 10
0006          ACOS = PI2
0007          RETURN
0008   10     C = B/A
0009          D = ATAN (C)
0010          IF (A.LT.0.0) D = D + PI
0012          ACOS = D
0013          RETURN
0014          END
```

```
      SUBROUTINE WALTEM (F,DTINE,DUM1,DUM2)
      COMMON RUNID(5),RTITLE(18),DATE(3),OPERN(5),PROPN(18),
     1 FSORCE(18),PRLOT(18),PREM(18),TIGNR(18),GAGE(18),
     2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
     3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
     4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
     5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
     6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
     7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
     8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
     9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW,RATE,RL
      COMMON /KEVIN/ TE(35), XT(35)
      DIMENSION TMA(2), TTA(2), DELX(35), DT(35)
      DATA ISW6/0/,ALFA/.01091/,XK/.0006667/,DELX0/.0009/,FAC/0.3/
      TTA(1) = DUM1
      TTA(2) = DUM2
      TMA(1) = 0.0
      TSUM = 0.0
      DTIME = DTINE/1000.
      TMA(2) = DTIME
      IF (ISW6.EQ.0) GO TO 86
      IF (DELTCN - DTIME) 90,90,91
   91 DELTIM = DTIME
      GO TO 92
   90 DELTIM = DELTCN
   92 TSUM = TSUM + DELTIM
      IF (TSUM - DTIME) 93,93,95
   95 TSUM = TSUM - DELTIM
      DELTIM = DTIME - TSUM
      TSUM = TSUM + DELTIM
   93 CONTINUE
      MEM7 = 1
      IF ((TMA(2)-TMA(1)).EQ.0.0) GO TO 1942
      CALL FIND1 (TSUM,TG,TMA,TTA,2,MEM7)
      GO TO 1943
 1942 TG = TTA(1)
      GO TO 1943
 1943 QDOT = F*(TG - XT(1))
      QDOT = QDOT + SPACE2(3)*(TG**4 - XT(1)**4)
      TZERO = QDOT/XK*2.*DELX0 + XT(2)
      DT(1) = ALFA/(DELX0**2)*(TZERO - 2.*XT(1) + XT(2))
      DO 42 I = 2,31
      CON17 = CONA/(DELX(I)**2)
   42 DT(I) = CON17*(XT(I-1) - CONB*XT(I) + CONC*XT(I+1))
      DO 5 I = 1,31
    5 XT(I) = XT(I) + DELTIM*DT(I)
      XT(32) = XT(30)
      IF (TSUM - DTIME) 92,74,74
   74 DELTIM = DTIME
      RETURN
   86 ISW6 = 1
      DO 21 I = 1,35
```

```
      XT(I) = 298.
   21 TE(I) = 298.
      TYPE 777, ALFA
  777 FORMAT (5X,'BOMB THERMAL DIFFUSIVITY',F12.5)
      ACCEPT 778, TEMP
```

```
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0051    778  FORMAT (E12.0)
0052         IF (TEMP.NE.0.0) ALFA = TEMP
0054         CONA = ALFA/(1. + FAC/2.)
0055         CONB = (2. + FAC)/(1. + FAC)
0056         CONC = 1./(1. + FAC)
0057         J = 1
0058         DWEB = DELX0
0059         DELX(J) = DELX0
0060         DO 22 J = 2,34
0061         DELX(J) = DWEB
0062     22  DWEB = DWEB*(1. + FAC)
0063         DELTCN = 0.35*DELX0**2/ALFA
0064         RETURN
0065         END
```

```
0001          SUBROUTINE RCALC
       C      SUBROUTINE TO DO LEAST SQUARES FIT ON BURN RATE DATA
0002          COMMON RUNID(5),RTITLE(10),DATE(3),OPERN(5),PROPN(10),
             1 PSORCE(10),PRLOT(10),PREM(10),TIGNR(10),GAGE(10),
             2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
             3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
             4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
             5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
             6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
             7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
             8 CON1,CON9,MEM3,MEM7,SFAC,L9,P1,DP1,TSTOP,I9,
             9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW
0003          DIMENSION T(400),P(400),DP(400),R(400)
0004          COMMON /BLAH/ PLO, PHI, ACO, XNC,RSQ, RMS
0005          REWIND 11
0006          DO 669 I = 1,L8
0007          READ (11,384) T(I),P(I),DP(I),R(I)
0008    384   FORMAT (4E13.6)
0009    669   CONTINUE
0010          PLL = PLO*PMAX
0011          PUL = PHI*PMAX
0012          K = 0
0013          SUM1 = 0.0
0014          SUM2 = 0.0
0015          SUM3 = 0.0
0016          SUM4 = 0.0
0017          SUM5 = 0.0
0018          DO 735 I = 1,L8
0019          IF (P(I).LT.PLL) GO TO 735
0021          IF (P(I).GT.PUL) GO TO 735
0023          K = K + 1
0024          DUM1 = ALOG (P(I)*1000.)
0025          DUM2 = ALOG (AMAX1(R(I),0.001))
0026          SUM1 = SUM1 + DUM1*DUM2
0027          SUM2 = SUM2 + DUM1
0028          SUM3 = SUM3 + DUM2
0029          SUM4 = SUM4 + DUM1**2
0030          SUM5 = SUM5 + DUM2**2
0031    735   CONTINUE
0032          XNC = (SUM1 - SUM2*SUM3/K)/(SUM4 - (SUM2**2)/K)
0033          ACO = EXP (SUM3/K - XNC*SUM2/K)
0034          RSQ = ((SUM1 - SUM2*SUM3/K)**2)/((SUM4 - (SUM2**2)/K)*
             1 (SUM5 - (SUM3**2)/K))
0035          SUM= 0.0
0036          K = 0
0037          DO 733 I = 1,L8
0038          IF (P(I).LT.PLL) GO TO 733
0040          IF (P(I).GT.PUL) GO TO 733
0042          K = K + 1
0043          DUM1 = ACO*(P(I)*1000.)**XNC
0044          DUM1 = (R(I) - DUM1)/AMAX1(R(I),0.001)
0045          SUM = SUM + DUM1**2
```

```
  733 CONTINUE
      RMS = SQRT (SUM/(K - 2))*100.0
      RETURN
      END
```

```
      C         VERSATRAN PLOTTER SUBROUTINE FOR CBRED
0001            SUBROUTINE VPLOT
0002            COMMON RUNID(5),RTITLE(18),DATE(3),OPERN(5),PROPN(18),
               1 PSORCE(18),PRLOT(18),PREM(18),TIGNR(18),GAGE(18),
               2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
               3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
               4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
               5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
               6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
               7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
               8 CON1,CON9,MEM3,MEM7,SFAC,L9,P1,DP1,TSTOP,I9,
               9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW
0003            DIMENSION T(400),P(400),DP(400),R(400)
0004            COMMON /BLAH/ PLO, PHI, ACO, XNC, RSQ, RMS
0005            DIMENSION ABC(17)
0006            DIMENSION BCD(15)
0007            DIMENSION A(11)
0008            DIMENSION T9(2), P11(2)
0009            DIMENSION X1(9),Y1(13)
0010            DIMENSION TIT(16)
0011            DATA TIT/'P/PM','AX  ','PDOT','    ','RUN ','ID: ','RUN ',
               1 'TITL','E:  ','PROP',' TYP','E:  ','GRAI','N TY','PE: ',
               2 'AT  '/, S/9999./
0012            DATA A/1.0,2.0,4.0,6.0,8.0,10.0,20.0,40.0,60.0,80.0,100.0/
0013            DATA X1/'TIME','-MSE','C   ','    ',4HP/PM,'AX  ','1.0 ',
               1 '10.0','100.'/,Y1/'PRES','S-KP','SIA ','PDOT',' MPS',
               2 4HI/SE,'C   ','0.1 ','1.0 ','10.0','RATE',4H-IN/,'SEC '/
0014            DATA ABC/'THE ','CONS','TANT','S IN',' THE',' EQU','ATIO',
               1 'N R ','= A*','P**N',' ARE','A:  ','N:  ','FOR ','P/PM',
               2 'AX  ',' TO'/
0015            DATA BCD/'COEF','FICI','ENT ','OF D','ETER','MINA',
               1 'TION',' :  ','PER ','CENT',' ROO','T ME','AN E','RROR',' :  '/
0016            REWIND 11
0017            DO 683 I = 1,L8
0018            READ (11,384) T(I),P(I),DP(I),R(I)
0019      384   FORMAT (4E13.6)
0020      683   CONTINUE
0021            ENDFILE 11
0022            CALL MODE (8,2.0,1.0,-1.)
0023            CALL MODE (2,8.0,-0.75,0.075)
0024            CALL MODE (3,6.0,-0.75,3.0)
0025            CALL MODE (7,5.0,5.0,S)
0026            TYPE 1976
0027      1976  FORMAT (5X,'DO YOU WANT TO SUPPRESS THE IGNITION'/
               1 5X,'TIME LAG ON THE PRESSURE AND DP/DT PLOT?'/
               2 5X,'TYPE ''S'' TO SUPPRESS')
0028            ACCEPT 1977, STS
0029      1977  FORMAT (A4)
0030            IF (STS.NE.STR) GO TO 1978
0032            DATA STR/'S'/
0033            T9(1) = 10.*IFIX(TIGN/10.)
0034            DUMA = 0.0
```

```
      GO TO 1979
 1978 T9(1) = 0.0
      DUMA = 5.0
 1979 T9(2) = TMAX
      P11(1) = 0.0
```

```
      P11(2) = PMAX
      CALL SCAN (T9, P11, -2, 440)
      CALL MODE (-8,DUM1,DUM2,DUM3)
      DUM2 = AMAX1(DUM2, DUMA)
      CALL MODE (8, DUM1, DUM2, S)
      DUM4 = DUM2
      DUM8 = DUM1
      CALL MODE (-9, DUM1,DUM2,DUM3)
      DUM2 = AMAX1(DUM2,5.0)
      CALL MODE (9,0.0,DUM2,S)
      CALL AXES (9.2,X1(1),11.2,Y1(1))
      CALL DRAW (T, P, L8, 440)
      CALL SCAN (T, DP, -L8, 440)
      CALL MODE (8,DUM8,DUM4,S)
      CALL MODE (-2,DUM1,DUM2,DUM3)
      DUM5 = DUM3 - 0.5
      CALL MODE (2,  S,S,DUM5)
      CALL MODE (9, 0.0, S, S)
      CALL AXES (-4.0,X1(4),13.3,Y1(4))
      CALL MODE (2,S,S,DUM3)
      CALL DRAW (T, DP, L8, 440)
      K = 0
      CALL MODE (4,.073,.055,S)
      CALL MODE (6,S,.080,S)
      CALL MODE (3,S,S,-.2)
      CALL NOTE (0.0,3.0,TIT(5),7)
      CALL NOTE (1.0,3.0,RUNID(1),20)
      CALL NOTE (0.0,2.8,TIT(7),10)
      CALL NOTE (1.0,2.8,RTITLE(1),60)
      CALL NOTE (0.0,2.6,TIT(10),10)
      CALL NOTE (1.0,2.6,PROPN(1),60)
      CALL NOTE (0.0,2.4,TIT(13),11)
      CALL NOTE (1.0,2.4,FFID,4)
      IF (K.EQ.0) GO TO 10
      CALL NOTE (0.0,2.2,TIT(3),4)
      CALL NOTE (2.0,2.2,TIT(16),2)
      CALL NOTE (4.0,2.2,TIT(1),6)
      Y = 2.2 - 0.2
      DO 61 I = 1,4
      CALL NOTE (0.0,Y,DP9(I),1003)
      CALL NOTE (4.0,Y,P9(I),1003)
61    Y = Y - 0.2
10    CALL MODE (4,.1,.067,S)
      CALL MODE (6,S,.1,S)
      CALL MODE (3,S,S,3.0)
      CALL DRAW (0.,0.,1,9000)
      PMAX = 0.0
      DO 65 I = 1,L8
65    PMAX = AMAX1(PMAX,P(I))
      DO 69 I =1,L8
69    T(I) = P(I)/PMAX
      CALL MODE (8, 0.0, 0.2, 0.0)
```

```
      CALL AXES (6.2,X1(5),13.3,Y1(4))
      CALL DRAW (T, DP, L8, 440)
      CALL FORM (5, 1.0, 5, 1.0)
      K = 1
      CALL MODE (4,.073,.055,S)
```

```
0098         CALL MODE (6,S,.080,S)
0099         CALL MODE (3,S,S,-.2)
0100         CALL NOTE (0.0,3.0,TIT(5),7)
0101         CALL NOTE (1.0,3.0,RUNID(1),20)
0102         CALL NOTE (0.0,2.8,TIT(7),10)
0103         CALL NOTE (1.0,2.8,RTITLE(1),60)
0104         CALL NOTE (0.0,2.6,TIT(10),10)
0105         CALL NOTE (1.0,2.6,PROPN(1),60)
0106         CALL NOTE (0.0,2.4,TIT(13),11)
0107         CALL NOTE (1.0,2.4,FFID,4)
0108         IF (K.EQ.0) GO TO 11
0110         CALL NOTE (0.0,2.2,TIT(3),4)
0111         CALL NOTE (2.0,2.2,TIT(16),2)
0112         CALL NOTE (4.0,2.2,TIT(1),6)
0113         Y = 2.2 - 0.2
0114         DO 81 I = 1,4
0115         CALL NOTE (0.0,Y,DP9(I),1003)
0116         CALL NOTE (4.0,Y,P9(I),1003)
0117    81   Y = Y - 0.2
0118    11   CALL MODE (4,.1,.067,S)
0119         CALL MODE (6,S,.1,S)
0120         CALL MODE (3,S,S,3.0)
0121         CALL DRAW (0.,0.,1,9000)
0122         PFAC = 1.0
0123         IF (PMAX.LE.10.0) PFAC = 10.0
0125         PMIN = 1.0
0126         PMIN = PMIN/PFAC
0127         IGO = 0
0128         PSTO = PMAX
0129         TYPE 529
0130   529   FORMAT (5X,'DO YOU WANT ALL THE RATE CURVE?'/
            1 5X,'ENTER 1 FOR YES, PLEASE')
0131         ACCEPT 530, IGO
0132   530   FORMAT (I1)
0133         IF (IGO.EQ.1) GO TO 533
0135         PMIN = PLO*PMAX
0136         PSTO = PHI*PMAX
0137   533   CONTINUE
0138         RMAX = 10.0
0139         RMIN = 0.1
0140         J97 = 0
0141         DO 68 I = 1,L0
0142         IF (P(I).LT.PMIN) GO TO 68
0144         IF (P(I).GT.PSTO) GO TO 68
0146         J97 = J97 + 1
0147         P(J97) = ALOG10 (AMAX1(P(I),PMIN))
0148         R(J97) = ALOG10 (AMAX1(AMIN1(R(I),10.0), 0.1))
0149    68   CONTINUE
0150         DUM1 = 0.0
0151         IF (PFAC.GT.1.0) DUM1 = -1.0
0153         CALL MODE (8,DUM1, 0.4,   S)
0154         CALL MODE (9, -1.0, 0.4,   S)
```

```
      DO 66 I = 1,10
   66 A(I) = 2.5*ALOG10(A(I+1)/A(I))
      CALL FORM (1010,A,1010,A)
      IF (PFAC.EQ.1.0) GO TO 997
      CALL NOTE (-0.1,-0.25,Y1(8),3)
```

```
      CALL NOTE (2.3,-0.25,Y1(9),3)
      CALL NOTE (4.7,-0.25,Y1(10),4)
      GO TO 998
997   CALL NOTE (-.1,-0.25,X1(7),3)
      CALL NOTE (2.3,-0.25, X1(8), 4)
      CALL NOTE (4.7,-0.25, X1(9), 4)
998   CONTINUE
      CALL MODE (4, S, S, 90.0)
      CALL NOTE (-.15,-.10, Y1(8), 3)
      CALL NOTE (-.15,2.40, Y1(9), 3)
      CALL NOTE (-.15,4.8, Y1(10), 4)
      CALL MODE (-4,DUM1,DUM2,DUM3)
      CALL MODE (4, .16,.10,S)
      CALL MODE (-6,DUM4,DUM5,DUM6)
      CALL MODE (6,S,.16,.213)
      CALL NOTE (-.35,1.75,Y1(11),11)
      CALL MODE (4, S, S, 0.0)
      CALL NOTE (1.90,-.51, Y1(1),11)
      CALL MODE (4,DUM1,DUM2,S)
      CALL MODE (6,S,DUM5,DUM6)
      CALL DRAW (P, R, J97, 442)
      K = 0
      CALL MODE (4,.073,.055,S)
      CALL MODE (6,S,.080,S)
      CALL MODE (3,S,S,-.2)
      CALL NOTE (0.0,3.0,TIT(5),7)
      CALL NOTE (1.0,3.0,RUNID(1),20)
      CALL NOTE (0.0,2.8,TIT(7),10)
      CALL NOTE (1.0,2.8,RTITLE(1),68)
      CALL NOTE (0.0,2.6,TIT(10),10)
      CALL NOTE (1.0,2.6,PROPN(1),68)
      CALL NOTE (0.0,2.4,TIT(13),11)
      CALL NOTE (1.0,2.4,FFID,4)
      CALL NOTE (0.0,2.2,ABC(1),44)
      CALL NOTE (0.0,2.0,ABC(12),3)
      CALL NOTE (1.0,2.0,ACO,1006)
      CALL NOTE (0.0,1.8,ABC(13),3)
      CALL NOTE (1.0,1.8,XNC,1003)
      CALL NOTE (0.0,1.6,ABC(14),11)
      CALL NOTE (1.0,1.6,PLO,1003)
      CALL NOTE(1.4,1.6,ABC(17),4)
      CALL NOTE (1.72,1.6,PHI,1003)
      CALL NOTE (0.0,1.4,BCD(1),31)
      CALL NOTE (2.40,1.4,RSQ,1004)
      CALL NOTE (0.0,1.2,BCD(9),27)
      CALL NOTE (2.48,1.2,RMS,1004)
      IF (K.EQ.6) GO TO 12
      CALL NOTE (0.0,2.2,TIT(3),4)
      CALL NOTE (2.0,2.2,TIT(16),2)
      CALL NOTE (4.0,2.2,TIT(1),6)
      Y = 2.2 - 0.2
      DO 91 I = 1,4
```

```
      CALL NOTE (0.0,Y,DP9(I),1003)
      CALL NOTE (4.0,Y,P9(I),1003)
   91 Y = Y - 0.2
   12 CALL MODE (4,.1,.067,S)
      CALL MODE (F.S,.1,S)
```

```
      CALL MODE (3,S,S,3.0)
      CALL DRAW (0.,0.,1,9000)
      CALL DRAW (0.0, 0.0, 0.0, 9999)
      RETURN
      END
```

```
RT-11 FORTRAN IV        V01-11  SOURCE LISTING          PAGE 001

0001          SUBROUTINE FINDTP (ARG, ANS, NVAR, NARG, NANS, IDEV, NPTS,I,MG)
        C     SUBROUTINE FIND.  TABLE LOOK-UP WITH LINEAR INTERPOLATION.
        C     FINDTP IS A DIRECT ACCESS READ LOOKUP MODIFICATION OF
        C     FIND.  INSTEAD OF AN ARRAY, PASSING THE ARGUMENTS, IT
        C     EXPECTS A FILE WHICH HAS BEEN FILLED WITH NVAR VARIABLES,
        C     TO THE EXTENT OF NPTS RECORDS.  THE INDEPENDENT
        C     VARIABLE MAY OCCUPY ANY OF THE LOCATIONS 1-NVAR AND
        C     NARG GIVES ITS LOCATION.  LIKEWISE FOR THE DEPENDENT
        C     VARIABLE WHOSE LOCATION IS GIVEN BY NANS.  IDEV GIVES
        C     THE DEVICE NUMBER OR FILE NUMBER WHICH WAS DEFINED
        C     IN SETTING UP THE FILE.  ALL OTHER FIND COMMENTS
        C     APPLY TO FINDTP.
        C     NOTE..... LIKE FIND, THE INDEPENDENT VARIABLE MUST
        C     BE MONOTONICALLY INCREASING.....
        C
        C      J. ANDERSON      6-1-65
        C             EXTRAPOLATES FOR VALUES OUT OF TABLE RANGE
        C             REMEMBERS LAST ARG VALUE AND BEGINS SEARCH FROM THAT VALUE
        C             CALLING SEQUENCE IS .....
        C
        C             CALL FINDTP (ARG,ANS,NVAR,NARG,NANS,IDEV,NPTS,I)
        C
        C                    ARG IS THE ARGUMENT
        C                    ANS CONTAINS RESULT ON EXIT
        C                    X IS ONE DIMENSIONAL ARRAY OF INDEP. VARIABLE
        C                    X IS ONE DIMENSIONAL ARRAY OF DEP. VARIABLE
        C                    NPTS IS NUMBER OF TABLE ENTRIES
        C                    MEM SHOULD BE INITIALIZED TO 1 - AFTER FIRST
        C                      CALL THE SUBROUTINE WILL PRESERVE VALUES IN IT
        C    VARIABLE WHOSE LOCATION IS GIVEN BY NANS.  IDEV GIVES
        C     THE DEVICE NUMBER OR FILE NUMBER WHICH WAS DEFINED
        C     IN SETTING UP THE FILE.  ALL OTHER FIND COMMENTS
        C     APPLY TO FINDTP.
        C     NOTE..... LIKE FIND, THE INDEPENDENT VARIABLE MUST
        C     BE MONOTONICALLY INCREASING.....
        C
        C      J. ANDERSON      6-1-65
        C             EXTRAPOLATES FOR VALUES OUT OF TABLE RANGE
        C             REMEMBERS LAST ARG VALUE AND BEGINS SEARCH FROM THAT VALUE
        C             CALLING SEQUENCE IS .....
        C
        C             CALL FINDTP (ARG,ANS,NVAR,NARG,NANS,IDEV,NPTS,I)
        C
        C                    ARG IS THE ARGUMENT
        C                    ANS CONTAINS RESULT ON EXIT
        C                    X IS ONE DIMENSIONAL ARRAY OF INDEP. VARIABLE
        C                    X IS ONE DIMENSIONAL ARRAY OF DEP. VARIABLE
        C                    NPTS IS NUMBER OF TABLE ENTRIES
        C                    MEM SHOULD BE INITIALIZED TO 1 - AFTER FIRST
        C                      CALL THE SUBROUTINE WILL PRESERVE VALUES IN IT
        C
0002          DIMENSION X(10),Y(10)
```

```
    1   READ (IDEV'I) (X(J), J = 1,NVAR)
        IF (X(NARG)-ARG)    4,2,2
      2 I=I-1
        IF (I-1) 3,3,1
      3 I=1
```

```
      GO TO 7
    4 K = I + 1
      READ (IDEV'K) (Y(J), J = 1,NVAR)
      IF (Y(NARG)-ARG) 5,7,7
    5 I=I+1
      IF (I-NPTS)    4,6,6
    6 I=NPTS-1
    7 K = I + 1
      READ (IDEV'I) (X(J), J = 1,NVAR)
      READ (IDEV'K) (Y(J), J = 1,NVAR)
      ANS=X(NANS)+(Y(NANS)-X(NANS))*(ARG-X(NARG))/(Y(NARG)-X(NARG))
      RETURN
      END
```

```
0001           SUBROUTINE FIND1 (ARG,ANS,X,Y,NPTS,I)
         C     SUBROUTINE FIND.  TABLE LOOK-UP WITH LINEAR INTERPOLATION.
         C      J. ANDERSON      6-1-65
         C             EXTRAPOLATES FOR VALUES OUT OF TABLE RANGE
         C             REMEMBERS LAST ARG VALUE AND BEGINS SEARCH FROM THAT VALUE
         C             CALLIN SEQUENCE IS .....
         C
         C                CALL FIND (ARG,ANS,X,Y,NPTS,MEM)
         C
         C                    ARG IS THE ARGUMENT
         C                    ANS CONTAINS RESULT ON EXIT
         C                    X IS ONE DIMENSIONAL ARRAY OF INDEP. VARIABLE
         C                    X IS ONE DIMENSIONAL ARRAY OF DEP. VARIABLE
         C                    NPTS IS NUMBER OF TABLE ENTRIES
         C                    MEM SHOULD BE INITIALIZED TO 1 - AFTER FIRST
         C                      CALL THE SUBROUTINE WILL PRESERVE VALUES IN IT
         C
0002           DIMENSION X(10),Y(10)
0003         1 IF (X(I)-ARG)    4,2,2
0004         2 I=I-1
0005           IF (I-1) 3,3,1
0006         3 I=1
0007           GO TO 7
0008         4 IF (X(I+1)-ARG) 5,7,7
0009         5 I=I+1
0010           IF (I-NPTS)    4,6,6
0011         6 I=NPTS-1
0012         7 ANS=Y(I)+(Y(I+1)-Y(I))*(ARG-X(I))/(X(I+1)-X(I))
0013           RETURN
0014           END
```

```
      SUBROUTINE SIMEQ (A,B,D,L,M,N)
C     SUBROUTINE SOLVING L EQUATIONS IN M UNKNOWNS WITH N SETS OF RIGHT-
C     HAND CONSTANTS. A(L,M) IS THE MATRIX OF COEFFICIENTS AND B(L,N) IS
C     THE MATRIX OF COLUMNS OF ANSWERS. ON RETURN FROM SUBROUTINE, A
C     CONTAINS ORTHOGONALIZED COLUMNS, B CONTAINS THE RESIDUALS, AND
C     D(M,N) CONTAINS THE SOLUTIONS. FOR MORE EQUATIONS THAN UNKNOWNS
C     THE LEAST-SQUARES SOLUTION IS OBTAINED, OTHERWISE THE SOLUTION IS
C     IN TERMS OF THE FIRST L LINEARLY INDEPENDENT VARIABLES. REQUIRES..
C     DIMENSION  A(15,15), B(15,15), D(15,15)
C     CALL SIMEQ (A, B, D, L, M, N)
      DIMENSION A(500,1), B(500,1), C(3,3), D(1,1)
      DO 701 I=1,M
      DO 700 J=1,M
  700 C(I,J) = 0.0
      DO 701 K=1,N
  701 D(I,K) = 0.0
      DO 702 J=2,M
      DO 702 I=1,L
  702 C(J,J-1) = C(J,J-1) +  (A(I,J)*A(I,J))
      DO 712 K=1,M
      DO 709 J=K,M
      DO 703 I1=1,L
  703 C(K,J) = C(K,J) + (A(I1,K)*A(I1,J))
      IF (K-J) 706, 704, 704
  704 IF (K-1) 709, 709, 705
  705 IF (1.E-7*C(K,K-1) - 1.E7*C(K,K)) 709, 712, 712
  706 C(K,J) = C(K,J)/C(K,K)
  707 DO 708 I2=1,L
  708 A(I2,J) = A(I2,J) - (A(I2,K)*C(K,J))
  709 CONTINUE
      DO 711 J2=1,N
      DO 710 I3=1,L
  710 D(K,J2) = D(K,J2) + (A(I3,K)*B(I3,J2)/C(K,K))
      DO 711 I4=1,L
  711 B(I4,J2) = B(I4,J2) - (A(I4,K)*D(K,J2))
  712 CONTINUE
      IF (M - 1) 715, 715, 714
  714 DO 713 I=2,M
      IT = M+1-I
      JT = IT+1
      DO 713 J=1,N
      DO 713 K=JT,M
  713 D(IT,J) = D(IT,J) - (C(IT,K)*D(K,J))
  715 RETURN
      END
```

```
      C     CPEVES.004  22-AUG-75
      C
0001        SUBROUTINE EVES(N,TPRNT)
      C     THIS SUBROUTINE SOLVES N SIMULTANEOUS FIRST ORDER DIFFERENTIAL
      C     EQUATIONS BY THE ADAMS METHOD.
      C     TO USE ...
      C    - WRITE A MAIN PROGRAM TO READ THE INPUT DATA AND PERFORM ANY
      C      DESIRED AALCULATIONS PRIOR TO THE INTEGRATION. AT THE POINT
      C      WHERE THE INTEGRATION IS DESIRED
      C           CALL EVES (N,TPRNT)
      C             WHERE N IS THE NUMBER OF DIFFERENTIAL EQUATIONS
      C                   TPRNT IS A ONE DIMENSIONAL ARRAY FILLED WITH PAIRS
      C                         OF VALUES TO CONTROL PRINTING (DESCRIBED IN
      C                         SUBROUTINE PRINT)
      C      EVES WILL TAKE CONTROL AT THIS POINT AND PERFORM THE INTEGRATION
      C      UNTIL THE USER-PROVIDED SUBROUTINES INDICATE THE UPPER LIMIT HAS
      C      BEEN REACHED, (BY SETTING N=0), THEN CONTROL WILL BE RETURNED
      C      TO THE MAIN PROGRAM
      C
      C   USER SUBROUTINES ...
      C
      C      EVES REQUIRES 3 USER-SUBROUTINES TO PERFORM THE INTEGRATION
      C
      C     -SUBROUTINE SETUP (T,Y,SIG,N)
      C      DIMENSION T(2),Y(N),SIG(N,3)
      C
      C      THIS SUBROUTINE SETS THE INITIAL CONDITIONS FOR THE INTEGRATION
      C      AND DEFINES THE ACCURACY REQUIRED IN THE SOLUTION.
      C          T(1) = STARTING TIME (ASSUMED 0.0 IF NOT SPECIFIED)
      C          T(2) = INITIAL TIME INCREMENT (ASSUMED 1.0E-5 IF UNSPECIFIED)
      C          Y(I) = INITIAL VALUES OF DEPENDENT VARIABLES, I=1,N
      C                 (ASSUMED 0.0 IF UNSPECIFIED)
      C          SIG(I,1) = REQUIRED ACCURACY FOR THE DEPENDENT VARIABLES.
      C                     I=1,N WHERE SIG=1.E-M INDICATES M SIGNIFICANT
      C                     FIGURES. (ASSUMED 1.E-3 IF UNSPECIFIED)
      C          SIG(I,2) = MINIMUM ABSOLUTE ACCURACY DESIRED=SIG(I,2)*SIG(I,1
      C                     ). THIS SUSPENDS THE REQUIRED NO. OF SIGNIFICANT
      C                     FIGURES IF THE ABSOLUTE VALUE OF THE INTEGRAL IS
      C                     LESS THAN THIS VALUE. ITS USE IS TO PREVENT USE
      C                     OF AN INORDINATELY SMALL STEP SIZE AS AN
      C     INSETUP (T,Y,SIG,N)
      C      DIMENSION T(2),Y(N),SIG(N,3)
      C
      C      THIS SUBROUTINE SETS THE INITIAL CONDITIONS FOR THE INTEGRATION
      C      AND DEFINES THE ACCURACY REQUIRED IN THE SOLUTION.
      C          T(1) = STARTING TIME (ASSUMED 0.0 IF NOT SPECIFIED)
      C          T(2) = INITIAL TIME INCREMENT (ASSUMED 1.0E-5 IF UNSPECIFIED)
      C          Y(I) = INITIAL VALUES OF DEPENDENT VARIABLES, I=1,N
      C                 (ASSUMED 0.0 IF UNSPECIFIED)
      C          SIG(I,1) = REQUIRED ACCURACY FOR THE DEPENDENT VARIABLES.
      C                     I=1,N WHERE SIG=1.E-M INDICATES M SIGNIFICANT
      C                     FIGURES. (ASSUMED 1.E-3 IF UNSPECIFIED)
```

```
C          SIG(I,2) = MINIMUM ABSOLUTE ACCURACY DESIRED=SIG(I,2)*SIG(I,1
C                     ). THIS SUSPENDS THE REQUIRED NO. OF SIGNIFICANT
C                     FIGURES IF THE ABSOLUTE VALUE OF THE INTEGRAL IS
C                     LESS THAN THIS VALUE. ITS USE IS TO PREVENT USE
C                     OF AN INORDINATELY SMALL STEP SIZE AS AN INTEGRAL
```

```
C                    LEAVES 0. (ASSUMED 0. IF UNSPECIFIED)
C          SIG(I,3) = THRESHOLD VALUE FOR THE VARIABLE I. EVES WILL HIT
C                    THIS VALUE EXACTLY DURING THE INTEGRATION AND LET
C                    THE USER ROUTINES KNOW THIS VALUE HAS BEEN HIT.
C                    (ASSUMED 1.0E+35 IF UNSPECIFIED)
C
C
C      SUBROUTINE DIFEQ (T,Y,DY,N,TPR)
C       DIMENSION  T(2),Y(N),DY(N),TPR(2)
C
C       THIS SUBROUTINE EVALUATES THE DERIVATIVE VALUES (DY(I)),AT EACH
C       PROPOSED STEP IN THE SOLUTION. ON EACH CALL,T(1) CONTAINS THE
C       CURRENT TIME, AND THE Y(I)S ARE THE CURRENT INTEGRATED VALUES.
C       THE RESULTS OF A CALL MAY BE REJECTED,AND THE STEP SIZE CUT IN
C       ORDER TO MAINTAIN ACCURACY, SO NO PERMANENT SWITCH SETTING SHOULD
C       BE MADE IN THIS ROUTINE, BASED ON PROPOSED VALUES
C
C
C      -SUBROUTINE PRINT (T,Y,DY,N,TPR)
C       DIMENSION  T(2),Y(N),DY(N),TPR(N+4)
C
C       THIS SUBROUTINE IS CALLED TO OUTPUT ACCEPTED VALUES DURING THE
C       INTEGRATION PROCEEDURE. THE FREQUENCY WITH WHICH IT IS CALLED
C       IS DEPENDENT ON THE NUMBER OF INTEGRATION STEPS,THE TPRNT ARRAY
C       SUPPLIED TO EVES BY THE MAIN PROGRAM, AND THE THRESHOLD VALUES
C       FOR VARIABLES SET IN SUBROUTINE SETUP AS FOLLOWS -
C          -THE TPRNT ARRAY CONSISTS OF PAIRS OF VALUES DELTA T AND TLIM
C           SUCH THAT DELTA T IS THE PRINT INTERVAL UNTIL TLIM IS REACHED
C           , WHEREUPON THE NEXT PAIR OF VALUES TAKES CONTROL.
C               IF DELTA T .EQ. 0 EVERY ACCEPTED POINT IS PRINTED
C               IF DELTA T .GT. 0 PRINTING OCCURS ONLY AT INTERVALS OF
C                                 DELTA T
C               IF DELTA T .LT. 0 PRINTING OCCURS AT EVERY ACCEPTED
C                                 POINT,BUT AMONG THESE POINTS ARE
C                                 INTERVALS OF ABS(DELTA T)
C
C          -REGARDLESS OF THE TPRNT CONTROLS,A CALL TO PRINT WILL OCCUR
C           EACH TIME A VARIABLE REACHES IT'S THRESHOLD VALUE.
C
C       THE TPR ARRAY HAS THE FOLLOWING INFORMATION WHEN PRINT IS CALLED
C           TPR(1)  CURRENT DELTA T FROM TPRNT ARRAY
C           TPR(2)  CURRENT TLIM FROM TPRNT ARRAY
C           TPR(3)  0 IF CALLED THRU ACCURACY CONTROLLED STEP SIZE.
C                   +J IF CALLED DUE TO VARIABLE J RISING TO ITS
C                         THRESHOLD VALUE
C                   -J IF CALLED DUE TO VARIABLE J FALLING TO ITS
C                         THRESHOLD VALUE
C                   N+1 IF CALLED AT SPECIFIED PRINT POINT
C           TPR(4)  CURRENT TIME STEP SIZE FOR INTEGRATION
C             (IF THIS VALUE IS CHANGED IN PRINT, THE DIFFERENCE TABLE
C              WILL BE ZEROED AND THE SOLUTION RESTARTED WITH THE ALTERED
C              VALUE AS THE STEP SIZE. THIS IS TO GET AROUND EXTERNALLY
```

```
C            INDUCED DISCONTINUITIES WITHOUT REQUIRING THE INTEGRATION
C            TO DISCOVER THE POINT OF OCCURRENCE BY HALVING ITS STEP.)
C         TPR(5)  ROUGHEST VARIABLE OF CURRENT STEP
C         TPR(6)-TPR(N+5) CURRENT THRESHOLD SETTINGS FOR EACH VARIABLE
C                      (ALLOWING DYNAMIC RESET OF THRESHOLDS)
```

```
C
C
      DIMENSION D1(12,7),T1(2),D2(12,7),T2(2),Y1(12),DY1(12),SIG(12,3),
     1 Y2(12),DY2(12),TPRNT(6),TPR(17)
      DIMENSION T3(2)
      EQUIVALENCE (D1(1),Y1(1)),(D1(13),DY1(1)),(D2(1),Y2(1))
     1 ,(D2(13),DY2(1))
      TBIAS=0.0
      KTERR=0
    1 M=N
    2 DO   4 I=1,M
      DO   3 J=1,7
      D1(I,J)=0.0
    3 D2(I,J)=0.0
      SIG(I,1)=1.0E-03
      SIG(I,3)=1.0E+35
    4 SIG(I,2)=0.0
      IPRNT=1
      T1(1)=0.0
      T1(2)=1.E-5
C
C     INITIAL SETUP COMPLETE. CALL IN THE PROGRAMMERS SETUP.
C
      CALL SETUP(T1,Y1,SIG,M)
      IF (M.LT.0) IPRNT = -M
      M = N
      TPR(1)=TPRNT(IPRNT)
      TPR(2)=TPRNT(IPRNT+1)
      TNEXT=T1(1)+ABS(TPR(1))
      ISWV=1
      TPR(3)=0.
      DO   5 I=1,M
      J=I+5
    5 TPR(J)=SIG(I,3)
    6 CALL DIFEQ(T1,Y1,DY1,M,TPR)
      IF (M) 64, 64,  7
    7 CALL PRINT(T1,Y1,DY1,M,TPR)
      IF (M) 64, 64, 8
    8 T2(1)=T1(1)+T1(2)
      T2(2)=T1(2)
C
C     PREDICT AHEAD BY ADAMS METHOD.
C
      DO   9 I=1,M
    9 Y2(I)=0.34861111*D1(I,6)+0.375*D1(I,5)+0.41666667*D1(I,4)+0.5*
     1 D1(I,3)+T1(2)*DY1(I)+Y1(I)
      T3(1)=T2(1)+TBIAS
      T3(2)=T2(2)
C
C     OBTAIN THE DERIVATIVES AT THE PROPOSED POINT.
C
      CALL DIFEQ(T3,Y2,DY2,M,TPR)
```

```
  701 TZSAVE=-300
      IF (M) 64, 64, 10
   10 EMAX=0.
C
C     DIFFERENCE AND COMPUTE CRITICAL (MAXIMUM) ERROR TERM.
```

```
      C
            DO  18 I=1,M
            D2(I,3)=T2(2)*(DY2(I)-DY1(I))
            DO  11 J=3,6
         11 D2(I,J+1)=D2(I,J)-D1(I,J)
      C
      C     DELETE DIVERGENT DIFFERENCES.
      C
            DO  15 J=3,5
            IF (ABS(D2(I,J+1))-ABS(D2(I,J))) 15, 12, 12
         12 IF (ABS(D2(I,J+2))-ABS(D2(I,J+1))) 15, 13, 13
         13 DO  14 K=J,6
         14 D2(I,K+1)=0.
            GO TO  16
         15 CONTINUE
            J=7
         16 XYZ=0.3*D2(I,J)/(SIG(I,1)*AMAX1(ABS(Y2(I)),1.0E-30,SIG(I,2)))
            IF (ABS(XYZ)-EMAX) 18, 17, 17
         17 EMAX=ABS(XYZ)
            JCRAP=I
            TPR(5)=I
         18 CONTINUE
      C
      C     DETERMINE IF ERROR IS WITHIN BOUNDS.
      C
            IF (EMAX-1.0) 30, 30, 19
      C
      C     ERROR TOO BIG. HALVE THE INTERVAL AND TRY AGAIN.
      C
         19 T1(2)=.5*T1(2)
      C
      C     CHECK FOR DELTA TIME INSIGNIFICANT.
      C
            IF (T1(1)/T1(2)-1.0E06) 27, 20, 20
         20 CONTINUE
      C
      C     DELTA TIME IS INSIGNIFICANT. TRANSLATE THE ORIGIN.
      C
            DO  21 IJAZZ=1,M
         21 Y1(IJAZZ)=Y2(IJAZZ)
            TBIAS=TBIAS+T1(1)+2.0*T1(2)
            T2(2)=0.
            T1(1)=0.0
            KTERR=KTERR+1
            IF (KTERR-4) 23, 22, 22
         22 TYPE 67, JCRAP
            RETURN
         23 TYPE 68, KTERR, JCRAP
      C
      C     RESTART THE SOLUTION.
      C
         24 DO  26 IJAZZ=1,M
```

```
      DO 25 JAZZ=2,6
   25 D1(IJAZZ,JAZZ)=0.
      DO 26 JAZZ=2,7
   26 D2(IJAZZ,JAZZ)=0.
      T3(1)=TBIAS+T1(1)
```

```
      T1(2)=1.E-5
      T3(2)=1.E-5
      CALL DIFEQ(T3,Y1,DY1,M,TPR)
      GO TO  8
   27 DO  29 I=1,M
      DO  28 J=1,6
   28 D2(I,J)=D1(I,J)
   29 D2(I,7)=0.0
      GO TO  55
C
C     CALCULATE DELTA T TO HIT THRESHOLD EXACTLY
C
   30 GO TO ( 31, 38),ISWV
   31 IPOLD=ABS(TPR(3))
      TPR(3)=0.
      TRATSV=1.0
      ITER1 = 0
      DO 36 I=1,M
      IF (I .EQ. IPOLD) GO TO 36
      IF (SIGN(1.0,(Y1(I)-TPR(I+5)))*SIGN(1.0,(Y2(I)-TPR(I+5))))
     1  32,32,36
   32 TDY3=0.25*D1(I,6)+0.33333333*D1(I,5)+0.5*D1(I,4)+D1(I,3)
      TDY4=0.1666667*D1(I,6)+D1(I,5)+D1(I,4)
      TDY5=1.5*D1(I,6)+D1(I,5)
      TDY6=D1(I,6)
      YTARG=TPR(I+5)
      ITER=0
      TRAT=0.5
      XINC=0.25
      IF (Y2(I) .LT. Y1(I)) XINC=-XINC
  700 YTEST=Y1(I)+TRAT*T3(2)*DY2(I)+TDY3*TRAT**2/2.0+TDY4*TRAT**3/6.0
     1 +TDY5*TRAT**4/24.0*TDY6*TRAT**5/120.
      IF (YTEST .GT. YTARG) TRAT=TRAT-XINC
      IF (YTEST .LT. YTARG) TRAT=TRAT+XINC
      XINC=XINC/2.
      ITER=ITER+1
      IF (ITER .LT. 30) GO TO 700
      IF (ITER1.EQ.0) TRATSV = TRAT
      TRATSV = AMIN1 (TRATSV, TRAT)
      ITER1 = 1
      TPR(3)=I
      IF (Y2(I) .LT. Y1(I)) TPR(3)=-I
   36 CONTINUE
      IF (ITER1.EQ.0) GO TO 38
   37 T1(2)=TRATSV*T1(2)
      ISWV=2
      GO TO 27
C
C     TEST FOR ERROR TOO SMALL
C
   38 T3(1) = T2(1) + TBIAS
      IF (EMAX -0.0015) 39,39,40
```

```
      C
      C     ERROR TOO SMALL. ACCEPT THIS POINT. BUT DOUBLE THE
      C        INTERVAL FOR THE NEXT POINT.
      C
0134     39 T1(2)=2.0*T2(2)
```

```
0135          GO TO  41
        C
        C     ERROR O.K. BUY THIS POINT AND MAINTAIN CURRENT INTERVAL.
        C
0136       40 T1(2)=T2(2)
0137       41 IF (TPR(3) .NE. 0.0) GO TO 73
0139          IF (TPR(1)) 42, 44, 45
0140       42 T3(1)=T2(1)+TBIAS
0141          T3(2)=T2(2)
        C
        C     OUTPUT THE ACCEPTED POINT.
        C
0142          TPR(4)=T3(2)
0143          IF (ABS((T3(1)-TNEXT)/TNEXT) .LE. 0.00001) TPR(3)=M+1
0145          TZSAVE=TPR(3)
0146          CALL PRINT(T3,Y2,DY2,M,TPR)
0147          ISWV=1
0148          IF (M) 64, 64, 43
        C
        C     TEST FOR PRINTING CONDITIONS.
        C
0149      43  IF (T3(2) .NE. TPR(4)) GO TO 200
0151          IF (ABS((T3(1)-TNEXT)/TNEXT)-0.00001) 47, 51, 51
0152       44 TNEXT=TPR(2)
0153       73 IF (T3(1) - TPR(2)) 46, 45, 46
0154       45 IF (ABS((T3(1)-TNEXT)/TNEXT)-0.00001) 99, 51, 51
0155      99  TPR(3) = M + 1
0156          TZSAVE=TPR(3)
0157      46  T3(2) = T2(2)
0158          T3(2)=T2(2)
0159          TPR(4)=T3(2)
0160          CALL PRINT(T3,Y2,DY2,M,TPR)
0161          ISWV=1
0162          IF (M) 64, 64, 47
0163      47  IF (T3(2) .NE. TPR(4)) GO TO 200
0165          IF (TZSAVE .EQ. TPR(3)) TNEXT=TNEXT+ABS(TPR(1))
0167          IF (T3(1)-TPR(2)+0.1*TPR(1)) 51, 48, 48
0168       48 IPRNT=IPRNT+2
0169          TPR(1)=TPRNT(IPRNT)
0170          TPR(2)=TPRNT(IPRNT+1)
0171          IF (TPR(1)) 49, 50, 49
0172       49 TNEXT=T3(1)+ABS(TPR(1))
0173          GO TO  51
0174       50 TNEXT=TPR(2)
0175       51 IF (T1(2)+T3(1)-TNEXT) 53, 53, 52
0176       52 T1(2)=TNEXT-T3(1)
0177       53 CONTINUE
0178       54 T1(1)=T2(1)
0179       55 W=T1(2)/T2(2)
0180          IF (W-1.0) 56, 65, 56
        C
        C     ADJUST THE DIFFERENCE TABLE FOR INTERVAL CHANGE.
```

```
C
   56 DO  57 I=1,M
      XYZ=W*W
      TMP3=D2(I,3)
      TMP4=D2(I,4)
```

```
      TMP5=D2(I,5)
      TMP6=D2(I,6)
      TMP7=D2(I,7)
      TMP3=(0.2*TMP7+0.25*TMP6+0.33333333*TMP5+0.5*TMP4+TMP3)*XYZ
      XYZ=XYZ*W
      TMP4=(0.83333333*TMP7+0.91666667*TMP6+TMP5+TMP4)*XYZ
      XYZ=XYZ*W
      TMP5=(1.75*TMP7+1.5*TMP6+TMP5)*XYZ
      XYZ=W*XYZ
      TMP6=(2.0*TMP7+TMP6)*XYZ
      TMP7=TMP7*XYZ*W
      Y1(I)=Y2(I)
      DY1(I)=DY2(I)
      D1(I,3)=0.83333333E-02*TMP7-0.416666667E-01*TMP6+0.166666667*
     1 TMP5-0.5*TMP4+TMP3
      D1(I,4)=0.58333333*TMP6-0.25*TMP7-TMP5+0.5*TMP4+TMP3
      D1(I,5)=1.25*TMP7-1.5*TMP6+TMP5
   57 D1(I,6)=TMP6-2.0*TMP7
C
C     DELETE DIVERGENT DIFFERENCES.
C
   58 DO  63 I=1,M
      DO  62 J=3,5
      IF (ABS(D1(I,J+1))-ABS(D1(I,J))) 62, 59, 59
   59 IF (ABS(D1(I,J+2))-ABS(D1(I,J+1))) 62, 60, 60
   60 DO  61 K=J,5
   61 D1(I,K+1)=0.0
      GO TO  63
   62 CONTINUE
   63 CONTINUE
      GO TO   8
   64 RETURN
   65 T1(1)=T2(1)
      T1(2)=T2(2)
      DO  66 I=1,M
      DO  66 J=1,6
   66 D1(I,J)=D2(I,J)
      GO TO   8
   67 FORMAT (1H1,30X,50HMORE THAN THREE ORIGIN TRANSLATION DUE TO VARIA
     1BLE,I3,/5X,12HRUN ABORTED.)
   68 FORMAT (1H0/1H0,30X,22HORIGIN TRANSLATION NO.,I3,26X,15HDUE TO VAR
     1IABLE,I3,/1H0)
C
C     CLEAR DIFFERENCE TABLE AT CUSTOMERS REQUEST
C
  200 DO 201 IJAZZ=1,M
      DO 202 JAZZ=2,6
  202 D1(IJAZZ,JAZZ)=0.0
      DO 201 JAZZ=2,7
  201 D2(IJAZZ,JAZZ)=0.0
      T1(1)=T2(1)
      DO 204 I=1,M
```

```
  204 Y1(I)=Y2(I)
      T1(2)=TPR(4)
      CALL DIFEQ (T3,Y1,DY1,M,TPR)
      GO TO 8
      END
```

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